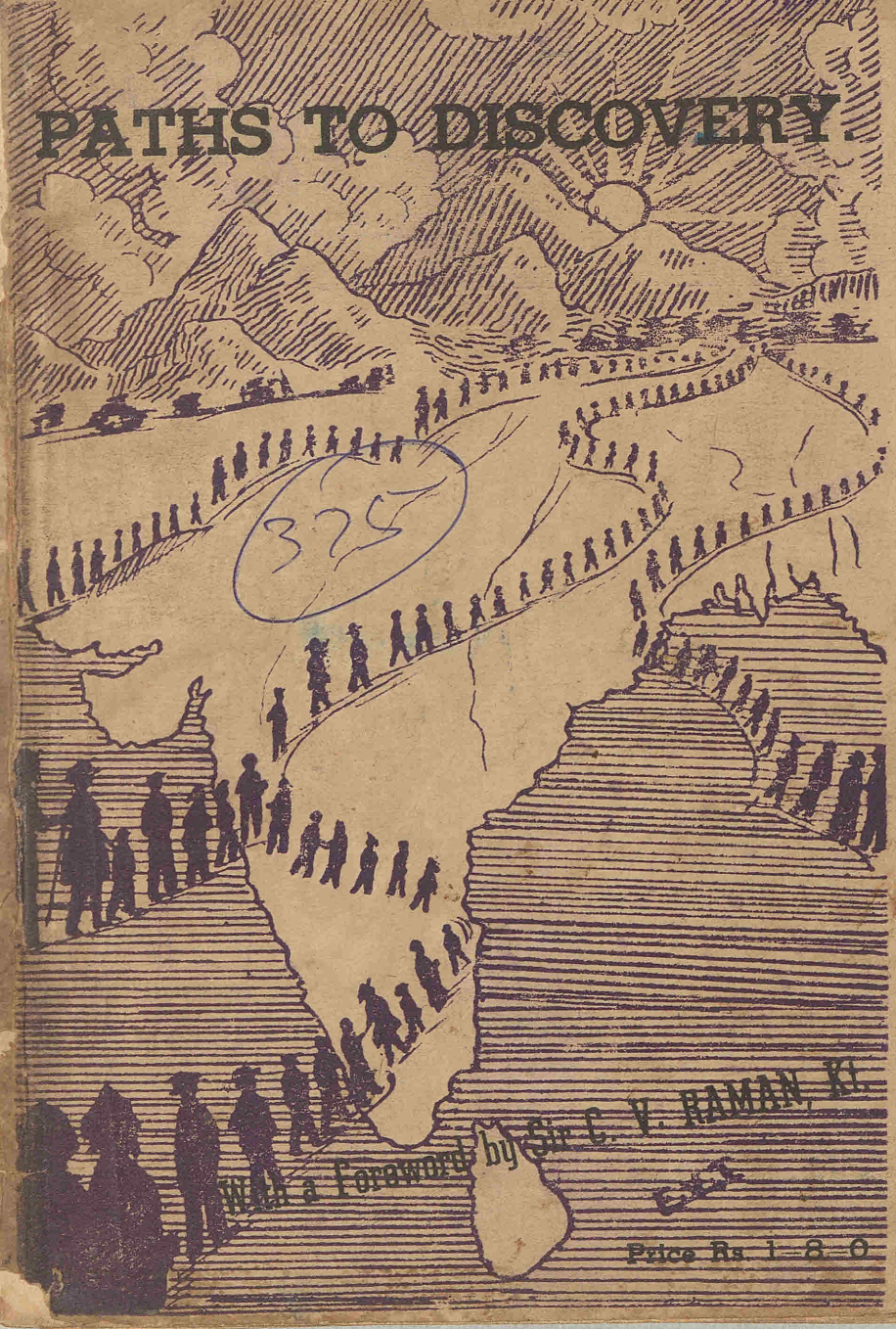
PATHS TO DISCOVERY



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With a Foreword by Sir C. V. RAMAN, Kt.

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NAVIRUL ISLAM HIGH SCHOOL
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Date.....
ERNAKULAM.

PATHS TO DISCOVERY

By

C. T. PHILIP, M. A., (Cal). M. A., Ed. (Lond.)

With a Foreword by Sir C. V. Raman, Kt.,

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TO MY FATHER

MUNAVIRUL ISLAM HIGH SCHOOL
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Date.....
ERNAKULAM

FOREWORD

By Sir C. V. RAMAN, Kt.,
M. A. Ph. D., D. Sc., F. R. S., N. L.

The story of scientific discovery may be told in diverse ways. Biographies of men of science and histories of the developments of special branches of science naturally include accounts of how great discoveries came to be made. In the book now before the reader, Mr Philip tells the story in his own way, and makes his points with the aid of numerous well-chosen examples. It is a very readable account which he has written. It is to be hoped that the book will be widely read by young students, and help to interest them in science and scientific research.

Indian Institute of Science,
Bangalore.

C. V. RAMAN.

PREFACE.

"Paths to Discovery" is a collection of some of the most interesting discoveries in science, so arranged and presented as to bring to light the circumstances leading to them and the mode of research pursued. The most interesting part of the biography of a scientist is, admittedly, the answer to the question which at some time or other occurs to the thoughtful reader, "How did he discover such wonderful things?" To emphasize this aspect of discovery a departure has been made from the usual practice of grouping the discoveries under their authors, or the branches of science to which they belong. They are classified in this book according to the quality of the discoverer, his method of work, or way of thinking that stands out as the dominant feature of the achievement. In fact the book is a string of examples to illustrate the various methods of attaining scientific truth. As there is no book within the knowledge of the author dealing with the subject in this way, he feels justified in adding yet another volume to the literature on discovery.

An attempt is made here to dispel the air of foggy mystery which laymen usually associate with scientific discoveries. By bringing them in line with the mode of thinking of young people for whom this book is intended, and making them appear as simple as possible consistently with accuracy, it is hoped the young reader would feel at home in the achievements of great scientists. The discoverers themselves are treated as ordinary men to be understood and emulated, rather than as prodigies to be placed on a pedestal and worshipped.

No distinction is made in this book between discovery and invention. Though prominence is given to the great workers in pure science, those who have contributed to the amenities of life by useful inventions are not lost sight of. Edison, therefore, finds a place along with Davy; and Stephenson rubs shoulders with Faraday.

Books on scientific discoveries being usually written by foreigners, no mention is made in them of our national heroes. It is in the fitness of things that the future citizens of India should have some knowledge about our great scientists, as they are likely to have about our politicians, thanks to our daily press. It is hoped that the work and achievements of some of our foremost scientists described in this book would go some way in satisfying this need.

There is a distinct moral tone running right through the book. The vital role played by scientific research in the cultural and material development of a nation is being gradually recognized in India. The myriads of problems that await solution both in the pure and the applied science require the services of a band of young men and women who would take to science as their profession. It cannot be gainsaid that, to wake up young minds from lethargy and diffidence, nothing more stimulating could be imagined than the examples of the great pioneers of scientific research. If this book would inspire in young hearts a love for science, and kindle in them a desire for research, the author would be highly gratified.

C. T. PHILIP.

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CHAPTER I

LOVERS OF SCIENCE.

Ever since the dawn of civilization the course of man's history has been illumined by the lives of a few men, who loved knowledge for its own sake. Without falling in with the herd in life's feverish race, they stood by and inquired into the meaning of things. While the common people wore out their lives some in the pursuit of riches, some in the pursuit of pleasure and the majority in the grinding struggle for existence, these great souls lived a life apart. Among them the great men of science occupy a supreme place. It was their constant delight to unravel the mysteries of Nature. They took pleasure in observing Nature in her ever-changing moods. They reduced the facts of their observation to order and harmony, and tried to understand in however small a measure the mind of the grest Designer.

Too far in advance of their age, they were misunderstood, criticized and sometimes persecuted by the multitude. Far from being dispirited by such opposition, they marched ever forward holding aloft the torch of truth. Little by little they wrested from Nature her innermost secrets, and reared up the magnificent edifice of scientific truth. What was it that led these great souls to turn aside from the beaten track and explore the wonders of Nature ? It was nothing but an intense desire to

know the uuknown. Their lives were a lovely expression of this yearning; and all their labours were inspired by this noble purpose.

A sweet note of joy runs through the writings of the great men of science. The following extract, taken from the notes of a chemist of the mediæval period, bears eloquent testimony to the cheering effect of science on the minds of men, even in those dark ages. "The chemists are a strange class of mortals, impelled by an almost insane impulse to seek their pleasure among smoke, vapour, soot and flame, poisons and poverty; yet among all these evils seen to live so sweetly, that may I die, if I would change places with the Persian King."

The following taken from a naturalist's dairy breaths the same spirit. "The wonders of Nature have been the delight and solace of my life. From the day when I first saw an orchid in ignorant astonishmet, to my first view of the grand forests of the Amazon, Nature has afforded me an ever-increasing rapture; and the attempt to solve some of her myriad problems, an ever-growing sense of mystery and awe."

Robert Boyle, the great English scientist, feared to die only because after death he would know all things, and no longer have the delight of scientific investigation. He once wrote: "In my laboratory I forget everything except the joy of making experiments." The rapturous effusions of Scheele strike the same note. "Oh! how happy I am. No care for eating or drinking, no care for my pharmaceu-

tical business, for that is mere play to me. But to watch new phenomena is all my desire and how glad is the inquirer when discovery rewards his diligence—then his heart rejoices." The zoologist who wrote, "I won't get tired so long as there is an undescribed intestinal worm or the riddle of a fossil-bone new to me," expressed the same spirit.

This overflowing enthusiasm for science was so truly inborn in them, that even in their childhood they showed unmistakable signs of it. The great American inventor, Thomas Edison, while yet a boy displayed such a keen avidity to perform experiments, that he gathered together all kinds of appliances and tools and set up a laboratory in the cellar of his house. He saved every penny that he earned by selling vegetables and newspapers to meet the cost of his chemicals. The bubbling energy of the boy is seen in the ambitious though crazy experiments he conducted. Once he induced a servant to take an enormous quantity of Sedleitz powder with a view to expand him by the gas produced. His idea was that if the body could be sufficiently expanded, men would be able to fly like birds.

On another occasion, he was busy constructing a model telegraph set. He collected the necessary iron wire and tied it up between posts in the lawn, but had no battery to get electricity from. Then it occurred to him that he had read somewhere that electricity could be generated by stroking a cat-skin. Off he ran and produced the

family cat and began stroking its furry back vigorously, with what consequences to his person, history does not record. Unfortunately, however, before the young telegraphist could proceed further, the circuit of wires and posts was dismantled by a cow grazing in the lawn.

Later, while working as a railway newspaper boy he obtained permission to use an empty brake-van as his laboratory. He brought all his bottles and glasses to the train and arranged them in the van. As his services were required only when the train stopped at stations, he got ample time to perform his experiments while the train was on the move. It so happened, that one day the train gave a violent jerk throwing down the assortment of chemicals, including a bottle of phosphorus which catching fire set the waggon ablaze. The infuriated guard stopped the train, walked up to the burning van, gave fhe young boy a sound box on the ear and threw out bottles, chemicals and all, to the utter dismay and depression of the amateur chemist. Quietly he gatherad together the remnants of his travelling laboratory and set them up in his cottage. These were the early signs of his keen love of research, which enabled him in due course to become the greatest inventor of his day.

Michael Faraday, the great English scientist, while an apprentice to a bookbinder felt such an indescribable fascination for every thing scientific, that he spent all his spare time consuming the contents of the scientific books that came to his

master for binding. As he read through the works of the great scientists, the glory of their achievements shone before his eyes like a distant holo, and impelled him to give up his job and join the happy band of scientists. A friend of his master noticing the scientific taste of the boy, took him to the Royal Institution to hear the lectures of Sir Humphry Davy the foremost scientific figure of his day. While he listened to the lectures of the great scientist, the youthful zeal for science that glowed fn his heart blazed into a raging flame. It became the great ambition of Faraday, to associate himself in however humble a manner with the Royal Institution.

With this object in view he made a summary of Davy's lectures from the notes he had taken and sent them to the great professor, accompanied by an application for a job in the Royal Institution. On consulting a friend about Faraday's application Davy received the advice : "Put him to wash bottles; if he is good for anything he will do that well." This was how Faraday got the ticket of entry to the laboratories of that great academy of research, wherein he was to achieve immortal glory and honour. What was it that this great discoverer—the father of electrical engineering, the founder of the science of electro-chemistry, the inventor of the dynamo—found so alluring in the Royal Institution, that he craved to work within its walls even if it were as a washer of bottles ?

No less romantic is the story of Ramanujan, the

South Indian boy, whose mathematical genius was a surprise even to Western scholars. Born in poverty and struggling hard to make both ends meet, he found circumstances uncongenial for any deep thought or study. And yet mathematics, the science of numbers, was his favourite hobby, and to reveal the inter relationships of the natural numbers his constant delight. Whether a student at college or a clerk in the port office, he used to spend all his spare time in meditation on the harmony of numbers.

The fame of Ramanujan's mathematical abilities soon spread far and wide. One of the professors of mathematics in the University of Combridge induced him to go over to England and spend a few years at Cambridge. An interesting incident which happened while he was in England, throws a flood of light on his intimacy with numbers. Once while he was confined to bed owing to illness, his professor paid him a visit. During their conversation the professor happened to mention that he had ridden in cab No. 1729, and expressed a fear that it was a dull and even an unlucky number. "No," replied the young mathematician, "it is the smallest number that can be expressed as the sum of two cubes in two different ways." * The positive integers were all his constant companions- He lived and had his being among them. It is indeed a great loss to India and

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* $1729 = 1^3 + 12^3 = 9^3 + 10^3$

to the world that this great mathematician passed away to the early age of thirty three.

Let us now turn to the fifteen year old boy James Watt whose name will ever be remembered in connection with the steam engine. We see him sitting at his evening tea. He is observing with searching eyes the steam escaping from the kettle on the table. Now he places a spoon at the spout watching the drops of water condensing on it; now his attention is diverted to the shivering lid, which he occasionally lifts up to let out the steam. His aunt, sitting near-by, unable to bear it any longer comes down upon the poor boy with the reproof: "I never saw such an idle boy. Take a book or employ yourself usefully. For the last one hour you have been doing nothing but playing with the kettle." Little his aunt realize then, that through the brain of the young boy were passing ideas which were destined to play such an important part in the evolution of the steam engine. What was it that revited the interest of the young boy to the power of steam? It was the first glow of that zeal for scientfic inquiry and invention, which enabled him in the fulness of time to present to the world an efficient instrument of mechanical power.

Or let us ask George Stephenson why after working all day long in the collieries, he spent sleepless nights at home in the construction and perfection of a locomotive to run on rails. A fireman's son, whose ambition as a boy was to become

a fireman, he caught the vision of a train running rapidly on rails. Engnieers scoffed at him saying that the wheels would fly away from the rails while running fast. "But the weight of the truck will make the wheels stick to the rails," replied Stephenson. He was sure that he was working on a sound principle. He did not feel dispirited, nor did he give up his efforts till his train ran on rails at the rate of 20 miles an hour. The colliery boy's childish craze for mechanics was thus carried through to a triumphant consummation.

About three decades ago, every evening a young man could be seen working in the physics laboratory of the Indian Association for the cultivation of Science in Calcutta. If you asked anybody who this nocturnal experimentalist was, you would have been told that he was a deputy accountant-general of Bengal. You could see him busy with his observations and measurements, none the worse for the daby's heavy work in the account office. University professors ply their test-tubes comfortably in well-equipped laboratories. Ambitious students work day and night grappling with some scientific problem in expectation of their degrees. But what has a deputy accouutant-generai to do wifh mirrors and lenses? What lured this young man from the comforts of a cosy home to the grim toil of the laboratory? He was a lover of science and the fetters of official duties could not keep him away from his beloved subject.

The Vice-Chancellor of the Calcutta University was so much taken with the young man's devotion to science, that he called the young officer and asked him whether he would give up government service to dedicate his life to scientific research. The deputy accountant-general made a generous response to the call of science, preferring the shifting fortunes of a scientific career to the glamours of the Indian Finance Service; and never had he to regret his choice. He is none other than Sir C. V. Raman, the celebrated Indian physicist.

Many more instances could be given of men who were enthralled by the spirit of science early in their lives. Take again the life of that marvellous English boy, Isaac Newton, who saw an apple falling down one day while sitting under an apple tree in his garden, and divined the mysteries of the motions of heavenly bodies. He was so much interested in scientific pursuits that he lived the life of a recluse always pondering and reasoning. Tycho Brahe, while he was a young boy, was so much impressed with the occurrence of a solar eclipse punctual to prediction, that he decided to dedicate his life to astronomy. Davy, Pasteur, Darwin and all the rest of them have similar tales to tell us. If we ask these great men why they consecrated their lives to science, they would answer in one chorus: "We fell in love with Science and abandoned ourselves to her charms."

CHAPTER II

SINGLE-HEARTED DEVOTION.

The great lovers of Science were not only charmed by her, but were chastened and ennobled in her service. They identified themselves so completely with her cause that they could not be swayed by any ulterior motive. Their single-hearted devotion to science raised them clean above any love of money. Louis Pasteur, the founder of the modern system of prevenitive medicine, is reported to have said that he could never work for money. He felt that he lowered himself by doing so. If he had chosen to take a patent for his discoveries he would have died a wealthy man; but he disdained to use the fruits of his research for financial gain and died a poor man.

Faraday once told a friend how at a certain stage of his career, when the importance of his discoveries was being recognized by the commercial world, he was faced with the dilemma of choosing wealth or science as the end of his life. To bring out the gravity of the situation, it may be mentioned that Farady obtained a thousand pounds that year from technical advice given to manufacturers, whereas his annual income as a professor in the Royal Iustitution was a mere hundred pounds. Yet he decided to give up commercial practice so that he could devote all his time to his experiments. Between money and science he chose the latter and died a poor man.

If he had so desired he could have amassed untold wealth; but science would have lost one of her most ardent votaries.

Sir Humphry Davy, whose name has become famous by his safety-lamp, when asked why he did not take a patent for his invention and earn five or ten thousands out of it, replied: "No, my good friend, I never thought of such a thing. My sole object was to serve the cause of humanity, and if I have succeeded, I am amply rewarded in the gratifying reflection of having done so."

The safety-lamp came as a great boon to colliery workers. At that time the coal-mining industry had fallen into evil days, owing to frequent explosions and consequent loss of lives in the mines. An inflammable gas issuing out of the fissures of coal seams used to form a dangerously explosive mixture, when mixed with the air inside the mines. When the workers got down the mines with small oil lamps to light their path, the mixture exploded causing death and destruction. Davy discovered that a lamp surrounded by a thick metallic wire-gauze did not set fire to the inflammable gas outside. The gas might get into the lamp and burn inside, but the flame could not get out through the wire-gauze. For if it attempted to do so, the metal wire-gauze being a good conductor of heat would cool it down. It was the discovery of the safety-lamp that restored the threatened coal mining industry to its original importance. If Sir Humphry Davy had not been a pure child of

science, he would have seized this opportunity to turn the discovery to financial gain.

Until a few years ago visitors to the University College of Science, Calcutta, could see an old emaciated man, moving about in the laboratories clad in a loin cloth. They would have had the surprise of their lives when they were told that he was Sir P. C. Ray, the great pioneer of Scientific research in India. As a young student he was very much interested in literature. But a few years of scientific training won him over to the cause of science. Ever since, he devoted all his energy to the advancement of science. He was alike a pioneer of chemical research and chemical industry in India. When research was practically unknown in this land, he started a school of chemical investigation. Almost all the chemists who have distinguished themselves in the various research centres in India drew their inspiration from this remarkable man. It was again he who laid the foundation of chemical industry in India by starting a chemieal factory in Calcutta with a few hundred rupees as capital; it is now worth lakhs.

In spite of his manifold humanitarian interests once he entered the laboratory, he forgot all about the outside world. In 1919 he was asked by his friends to stand for the reformed Legislative Council; but he declined saying; "I am deeply interested in politics and I should like to do so many things. But there are too many politicians in India and too few chemists. I cannot leave

chemistry for politics." When asked by a visitor whether he was married, he is reported to have replied with a smile: "As soon as I got my degree I took my test-tube and shut myself up in the laboratory. And when I came out after twenty years I discovered that I have forgotten to marry."

Sir P. C. Ray is a good example of a sincere worker untainted by financial motives. A retired government officer, the University Professor of Chemistry and a shareholder of many industrial concerns, he earned several thousands a month. Yet his personal needs were few. Two or three racks of books, a miserable-looking bedstead, an antiquated table and a few old-fashioned chairs were all his earthly belongings. He spent all his money on science, education and social service. Never more shall his frail figure be seen moving along the verandas of the University College. But he lives in the hearts of his students, friends and admirers, a noble soul ever inspired by lofty ideals.

Nor was it love of fame that induced the great scientists to pour out their lives in the service of science. Once a correspondent asked permission of Newton, to publish the solutions of certain mathematical problems which the latter had worked out. Newton, then at the age of twenty-seven, when desire for a certain amount of publicity would be natural to anyone, gave his permission, but reluctantly, and on the condition that his name should not be divulged. The same modesty characterized him throughout his life. When he made

a discovery or invented an instrument he kept it to himself for years, till some friend brought it to the notice of scientific circles.

Imagine the humility of a mind which conceived the grand idea of the Law of Gravitation, which regulates the motions of giant stars trillions of miles away from us, just as well as those of tiny pebbles rolling along the brook, and yet did not think it worth while to get it published. It was another astronomer, who happened to consult Newton on the motion of the moon, that disclosed to the world that Newton had already solved a problem which was then racking the brains of so many. He was like a strange diver, diving into the ocean of truth and coming out with what precious gems it offered, but not caring to turn them to profit. The diving was the thing for him and the yield of no concern.

Take again the English chemist, Cavendish, who was called "The richest among the learned and the most learned among the rich of his time." He was a scientist in the true sense of the word, the sole aim of his life being to unravel the mysteries of Nature, without caring a farthing for the honour and glory that followed in the wake of his discoveries. He would not even sit for a portrait. One persistent painter, bent upon getting the portrait of the bashful savant, sketched the outline of his body from memory, and had to watch his movements closely in order to snatch an opportunity to get in his facial features unnoticed.

Once in the house of a friend, Cavendish was introduced to a foreign visitor in very flattering terms. The foreign gentleman seconded all the praises and concluded his remarks by saying, that he had gone all the way to London to see Cavendish, one of the greatest ornaments of Britain and one of the illustrious philosophers of all time. Cavendish, nonplussed, fidgeted about for a moment in confusion, and taking advantage of an opening in the crowd of guests hastened out of the house to the seclusion of his laboratory. Such was his horror of publicity.

Louis Pasteur was another scientific celebrity remarkable for his humility. He was nominated by the French Government to represent them at the International Medical Congress held in London in 1882. When Pasteur entered the congress hall for the opening ceremony the hall was full. He was duly received and conducted to the seat reserved for him on the platform. Seeing the whole house bursting into cheers he remarked rather disconcertedly, "It is no doubt the Prince of Wales arriving. I ought to have come sooner." "But it is you they are all cheering," explained the president of the congress. The applause increasing in intensity, Pasteur had to stand up and bow before that august assembly.

Among the true sons of science there is no scrambling for the spoils of battle, no feverish haste to be first in the field. Each worker toils hard and offers his quota to the temple of scientific.

truth. Once the discovery is made, it becomes the common property of humanity. The bricks are laid by worker after worker; but individual contributions are lost in the beauty of the complete edifice. Truth is what the scientist is anxious for and not his own contribution to it.

Almost at the threshold of his career, Louis Pasteur solved a problem connected with the properties of tartaric acid which had baffled Biot, a French chemist of renown, for thirty years. The old professor welcomed the young man's discovery with enthusiasm, untainted by the least semblance of jealousy. He caught the budding chemist by the arm and exclaimed, "My dear boy, I have loved science so much during my life that this touches my very heart." Sir P. C. Ray once said in a speech that he considered it a great privilege to be beaten by his own students in the field of research.

It is not very rarely that a discovery is contradicted or superseded by more careful and efficient experiments. On such occasions the original discoverer yields magnanimously to the rising tide of knowledge. There is no clinging to obsolete ideas, no sticking to one's pet theories, as with those who "though vanquished argue still."

Towards the end of his life, Charles Darwin wrote about his great master-piece, "The Origin of Species," which embodies the major part of his life's work: "I look on it as absolutely certain that much in the 'Origin' will be proved rubbish.

But I expect and hope that the framework will stand." Darwin regarded his brilliant contribution to the problem of organic evolution not as irrefutable truth but as the groundwork for posterity to build on. Discoveries may be refuted and discoverers forgotten; but the frontiers of the realm of science are ever pushed forward.

After a life of ceaseless toil, the scientist does not sigh with the satisfaction of having achieved something, but wails that so little has been accomplished. Though his career was resplendent with phenomenal discoveries, Newton felt so unsatisfied with what he did, that he says in one of his writings that he was only a boy playing on the seashore, occasionally picking up a smoother pebble or a prettier shell than others, while the ocean of truth lay unexplored before him. Lord Kelvin, who was the foremost scientist of his day, said that if one word characterized his strenuous efforts for the advancement of science, during a period of fifty-five years, it was "failure". The inter-relationship of ether, matter and electricity in spite of all his attempts to unravel the mystery was as hidden to him then, as it was fifty-five years ago.

In spite of the profound devotion and selfless service of scientists, the world has not been kind to them. The works of the pioneers of truth have been looked upon with scepticism and ridicule, and persecution has often been their sole reward. Bruno was burnt at the stake for proclaiming scientific truth in defiance of authority. He taught

that the stars were suns like our own with their own planets. This was treason in the eyes of the custodians of the culture and religion of the sixteenth century ; and where ignorance was bliss it was misfortune for Bruno to be wise.

Galileo, an Italian savant, was imprisoned for no greater sin. Broken-hearted, blind and shattered in health, he spent his last years in misery and solitude. When the merciful hand of death relieved him from the ordeal, the authorities prohibited any monument to his memory. They threatened to carry away his bones if his friends attempted one. In that way they hoped to blot out the influence of his doctrines for ever. Yet in the same year an infant was born in England—Isaac Newton—who was destined to revive and perfect the work of their victim. Little did they know that the force of darkness could not hold sway for long.

Kepler, the great astronomer, had to struggle hard with poverty all through his life. His meagre salary as professor was always in arrears. Neither his contrymen nor the government did anything to support him. There was a proposal on his death to erect a marble monument to his memory but it fell through. No wonder that his countrymen, who did not give him bread while he lived, cared no more to give him a stone after his death.

Lavoisier was a great French chemist who lived at the time of the French Revolution. He was brought to trial during the Reign of Terror and sentenced to be executed. When an appeal

was made on his behalf to postpone the execution to give him time to complete some of his experiments, the ruthless judges refused the request saying : "The Republic has no need of chemists. Let the hand of justice work." Only a few years after that, the leaders of the French Revolution, hedged in by enemies and without proper methods of manufacturing explosives, realized but too well what chemists could do for the Republic.

When laymen realized the practical importance of scientific discoveries, they began to get interested in the labours of scientists. Their interest, however, was purely utilitarian. They viewed with no small amount of misgiving scientific research which did not lead to any useful purpose. The following incident throws a flood of light on the attitude of the public towards science in the early part of the nineteenth century. Faraday had just finished one of his lectures in the Royal Institution on the possibility of producing an electric current with the aid of a magnet, when a lady from the audience stood up and asked the lecturer : "But, Professor Faraday even if the effect you explained is obtained, what is the use of it ?" the memorable reply was, "Madam, will you tell me the use of a newborn child ?" Faraday's infant, by the way, has now grown into the dynamo giving light and warmth to millions. The lady did not voice the opinion of the man in the street alone ; for no less a person than Gladstone, the Prime Minister, once put the same question to Faraday :

"But after all, what is the use of your discovery?"

"One day you could tax it," replied the great professor good-humouredly, though in his heart of hearts Faraday who loved science for its own sake, felt a chilling sensation at the lack of public interest in what was so dear to his heart.

Nor did fortune always favour the men of science with health and vigour. Many scientists were not physically fit to undertake any arduous task. Nevertheless, far from bemoaning their lot they rushed on to the goal set before their eyes. Some of them had to struggle with ill-healfh all their lives. The life of Kepler was a long story of domestic troubles, disease and poverty. It is very remarkable, indeed, that he could turn out so much work in the midst of such calamities. His eyesight having being injured in his youth owing to illness, the telescope was a forbidden fruit to him. Yet he loved astronomy so much that he decided to work on the results of others' observations. The story is told of another astronomer who, being lame, arranged to be carried up the Alps in a chair to make certain astronomical observations from its top. Charles Darwin was an invalid throughout his life. We have it from his son, that he did not enjoy what is ordinarily called normal health for a single day of his life. James Watt had week nerves from his childhood; and severe headache prostrated him for days at a time. When Sir Isaac Newton was born, he was such a weakling that it was hardly hoped he would survive.

സ്ഥാനത്തു ഇരിക്കാൻ പാടില്ല. ഖുർആനെ മറവുള്ളവർ നിസ്സാരമാക്കാനും ഇടയാക്കരുതു്.

(25) അമ്പിയാക്കൾ, അവുലിയാക്കൾ, മത പണ്ഡിതന്മാർ തുടങ്ങിയവരെ ബഹുമാനിക്കണം.

(26) സജ്ജനങ്ങൾ അല്ലാഹുവിന്റെ ആജ്ഞകളെ അനുസരിക്കുകയും, അഹോരാത്രം അവനെ ആരാധിക്കുകയും ചെയ്യുന്നു. നിങ്ങളും അപ്രകാരം നല്ലവരാകാൻ ശ്രമിക്കണം.

(27) എല്ലാ മഹാന്മാരേയും ബഹുമാനിക്കുകയും അവരുടെ മുമ്പിൽ മര്യാദയായി സംസാരിക്കുകയും ചെയ്യുക.

(28) ബുദ്ധിമാനും, സന്മാർഗ്ഗിയും, സൽസ്വഭാവിയും, സത്യവാനുമായ സ്നേഹിതനെ തിരഞ്ഞെടുക്കണം.

(29) സ്നേഹിതന്മാരെ എപ്പോൾ കണ്ടാലും സലാം പറയണം. അവർ വീട്ടിൽ വന്നാൽ ബഹുമാനിക്കുകയും സൽക്കരിക്കുകയും ചെയ്യണം.

(30) വീട്ടിലെ കാര്യങ്ങൾ പുറത്തിറങ്ങി അന്യരെ അറിയിക്കരുതു്.

(31) ജനങ്ങളുടെയിടയിൽ സഞ്ചരിക്കുമ്പോൾ കാലു മറവുള്ളവരുടെ ശരീരത്തിൽ തട്ടാതെ പ്രത്യേകം ശ്രദ്ധിക്കണം.

(32) തൊപ്പിയോ തലപ്പാവോ കൊണ്ടു തല മറയ്ക്കാതെ ഒരിക്കലും നടക്കരുതു്.

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they possessed. Those great souls were so much enthralled by the cause of science, that far from waiting for the realization of ideal conditions they idealized the grim realities of their lot.

Love of science is the fountain-head of discovery. One, who is moved by the desire to unravel the mysteries of Nature, is already on the high-road to scientific achievement. The great men of science gave themselves up so completely to scientific research, that they were never influenced by any ulterior motive. Nor did their enthusiasm wane in the face of hostile circumstances. It is such single-hearted devotion that has been responsible for the wonderful progress of science during the last few centuries.

CHAPTER III

TRIUMPH OF TOIL

Thomas Edison, the great American inventor, used to say, "Genius is two percent inspiration and ninety-eight percent perspiration." Though it is hard to fix percentages, it is beyond dispute that genius without sustained work is like fire without fuel, burning itself out in a moment. All great men of science were strenuous workers; and patient industry has often been the secret of their success.

Perhaps the most remarkable of the sterling qualities of Edison, that contributed to his signal success as an inventor, was his infinite capacity for work. He used to say that a job well done with interest was more beneficial than a month at the seaside. Edison did not believe in rest or sleep. According to htm sleep is a wasteful habit to which man has become addicted by his idleness, and no more necessary for him than disease. When stimulated by the joy of mechanical creation, he would work all night long. His laboratory was a regular bee-hive day and night. Even when he was ill and confined to bed, his mind would be active, grappling with some problem or other. Barely convalescent, he would be aglow with the joy of work, and would emerge from his room like a boy left free from school, to resume his normal life of days of laboratory work, nights of exhaustive

study and endless hours of pondering and reasoning.

When Edison became interested in a problem he gave his whole heart to it. Nothing more intensive can be imagined than one of those Edisonian encounters with a great problem. It was a sight to watch the old man aglow with the fighting spirit. A man half his age would have stood appalled before the intricacies of the problem. But our hero is all exhilaration, seeing nothing, hearing nothing, thinking nothing except something likely to throw some light on his problem. We have it from his wife, how, once when confined to bed owing to ill-health, his mind became absorbed in the rubber problem. He saw before his mental eyes the enormous quantities of rubber imported into America. His patriotism revolted against the idea. He racked his brains to find out a method to make the American rubber-tyre industry independent of the rest of the world. His mind was full of rubber all those days of physical debility. His life was a round of such Herculean struggles.

Louis Pasteur was only a boy of Eighteen at school, when he wrote home the following letter: "Dear sisters, work hard, love each other. When one is accustomed to work, it is impossible to do without it; besides, everything in the world depends on it." Work was his constant inspiration. He could never have turned out the vast amount of work that stands to his credit but for his diligence.

Pasteur toiled hard throughout the day ; and he used to call the interval of night "hours of waiting", which always seemed to move with leaden feet.

When the practical importance of his discoveries came to be widely recognized, the French Government conferred on him a life pension of 12,000 francs. Pasteur's health was far from satisfactory at that time. He had already had an attack of paralysis and he stood in danger of getting another by continuous work. So everybody thought that Pasteur would now retire to some pleasant villa to enjoy his pension. The great benefactor of mankind, however, would not contemplate any such step. He went back straight to his laboratory and continued his researches. Not to work was for him, to lose the meaning of life. He carried this rage for work to the end. On his death-bed he turned to his devoted pupils and asked them : "Where had you been ? What are you doing?" and ended with, "You should work."

Even the brilliant Sir Isaac Newton worked and meditated for eighteen hours a day. On one occasion he left his guests to get some more wine from the cellar, but forgot all about them and was found hard at work in his study. Once Newton had to put up with a very trying experience. A lighted candle which he had left in his room burned down and set fire to a manuscript, which contained the results of all his work on light and colour for twenty years. The great scientist was so upset that people thought he might lose his senses. But

when he was asked later by a friend about the sad mishap, he merely observed that he was obliged to do the calculations all over again. Imagine the patient industry of a man who, seeing the hard work of years burnt to ashes, instead of yielding to despair, treads the tedious path once again. Once he is reported to have said, "If I have done the public any service this way, it is due to nothing but industry and patient thought."

When Herschel the great astronomer was engaged in the construction of telescopes, he was so much absorbed in the work, that his sister used to attend on him persuading him to take his food. On one occasion, according to his sister, he did not take his hand from the lens he was grinding, for sixteen hours on end. During such strenuous work she had to feed him by putting the victuals into his mouth. At night Herschel would be out in the open air, gazing into the sky through his telescope, often occupying himself thus all night long.

The study of the habits and instincts of insects is a branch of science which taxes the patience of the naturalist to a degree astonishing to the layman. It is said of Fabre, the great French naturalist, that he used to watch the habits of insects from morn till night without any break. One morning three peasant women met him sitting on a stone at the bottom of a ravine, intently looking on the ground. At sunset when the peasant women returned, Fabre was sitting on the same stone and looking at

the same spot. "A poor innocent", cried one and all and made the sign of the cross. A man sitting all day long absorbed in the study of insects was an enigma to the peasant women. puzzle, riddle.

Everybody has heard about that wonderful metal called radium, so useful to the physician. Its discovery is a good example of a great work achieved through sustained diligence. The closing years of the last century saw the discovery of radio-active substances. These substances emit continuously and steadily certain kinds of rays, the existence of which can be detected by means of suitable instruments.

In the course of her comparative study of the radio-activity of different substances, Madame Curie came across a sample of a mineral which showed the effect to an unusual extent. The radio-activity of the mineral was attributed to an extremely small proportion of a known element called uranium contained in it. But the particular sample mentioned showed much more radio-activity than could be accounted for by its uranium content. This suggested that traces of an unknown element, far more radio-active than uranium, should be present in the mineral. To isolate this new element from the mineral was like recovering a lump of sugar dissolved in an ocean of water. It was this stupendous task that Madame Curie took upon herself.

Starting with tons of the mineral, Madame Curie removed the non-radio-active ingredients.

little by little, by taking advantage of the differences in ihe solubilities of the various components of the mineral. If, for example, part of the mineral was rendered soluble in a liquid, and if by suitable tests it was found that the insoluble part was no longer radio-active, it might be thrown away and the radio-active ingredient searched for in the dissolved part. Working on thus Madame Curie conentrated all the radio-activity of the mineral to a small bulk. Towards the latter part of the research, she found that the supposed radio-active substance stuck on to some of the ingredients so tenaciously, by reason of the close similarity in their properties, that separation seemed well-nigh impossible. But our heroine worked on steadily and patiently. Mountains of mineral gradually shrank to mole-hills. At last after several years of painstaking and patient experiments, Madame Curie was able to isolate a few grains of the elusive metal. On account of its intensive radio-activity it was called radium The isolation of radium by Madame Curie is unigue in the annals of science, as it was the first time that a woman made a great scientific discovey. In recognition of her meritorious work she was awarded the Noble prize, which is given year after year to men and women who distinguish themselves by glorious achievements.

Chemists have shown by analysis that milk consists of water, sugar, fat and a few other substances. When pure samples of these substances

were mixed up in the right proportion, they got a liquid which appeard to be milk to all intents and purposes. Milk is well-known as the ideal food on which all animals can thrive. When, however, some mice were fed entirely on the artificial milk prepared as above, none on them lived longer than a month. So it became clear that milk contains traces of some other substance vital to animal life, but hidden from the chemist's view. It could be present in milk only in extremely minute quantities; because, otherwise it would have been detected long ago. Evidently it was evading the eagle eyes of the chemist, by taking cover under some of the other components of milk. Unable to insolate or understand the nature of this vital body, chemists did us at least the favour of giving it a name. It was called vitamin *A*; for there were ample reasons to suspect the existence of other similar bodies in plant and animal products.

Professor Drummond of London decided to fish out vitamin A from its usual hiding places. Finding that cod-liver oil was richer in vitamin A than milk, as shown by its copacity to promote growth in young mice, he proceeded to analyse cod-liver oil into its components. He found out that the vitamin, far from distributing itself among all the different components, adhered selectively to a few of them. Hence he was enabled to concentrate the vitamin to smaller and smaller bulk, by removing the vitamin-free components one by one. Starting with hundreds of gallons of cod-liver oil, as he did,

he had to work for several weeks to get a fraction rich in the vitamin. It taxed his patience to the extreme, filtering and distilling and treating with chemicals, all the time noting carefully by suitable tests the fraction to which the elusive vitamin adhered.

Professor Drummond toiled on like this concentrating the vitamin to smaller and smaller bulk, till at last he got a small quantity of an oily substance containing all the vitamin A present in the original cod-liver oil. He separated this into several parts by taking advantage of the differences in their boiling points. One of the fractions was found to be the long-looked-for vitamin A * The quantity of cod-liver oil that had to be-used was so enormous and the substance looked for was so minute that the work stands out as a superb achievement of enduring patience. Now that chemists have known what vitamin A is, it will not be long before artificial vitamin A is placed on the market cheaper than that obtained from any natural source

Those, who consider discoverers as extraordinary persons endowed with miraculous powers, may be surprised to know that the secret of many of their successes was dogged persistence in the solving of some problem, the perfecting of some appliance or the mastering of some experimental difficulty. Instance after instance could be mentioned of discoveries being made as a result of

* Vitamin A has since been obtained in a far purer state from halibut liver oil by Kaberr.

painful and repeated attempts. Nature often behaves as a shy maiden who reserves her smiles only for the persistent wooer. He who gets dispirited at her wonted frowns is not worthy of the kingdom of science.

Thomas Edison used to say: "There is nothing like luck for me. Most fellows try a few thing and quit. I never quit till I get what I want. I fail a hundred times and the hundred and first time I succeed. Some say I have genius. Nothing of the sort. Any other bright-minded fellow could have accomplished just as much as I did, if only he stuck to it." This was the secret, in his own blunt words, of the great success of this "Wizard of Invention." Infinite patience characterized all his research. Never would he accept defeat.

Once one of his assistants was engaged in the production of a suitable wax for the manufacture of gramophone plates. One night he sent for the assistant and told him: "We are all going to work throughout the night. Make up your mind that you won't go to sleep till we succeed." Many such nights did the assistant keep vigil over the plastic stuff simmering in his basin, and yet was he unable to prepare the right kind of wax. After a year of persistent assault the despondent lieutenant approached the indomitable general with the remark: "We had better give it up. There is no solution to the problem." Edison at once flared up: "Let us call ourselves fools. The Lord who has given us the problem has a solution too." And

he did not rest till he solved the prblem at last. When next we see a gramophone plate spinning merrily and releasing the melodious music imprisoned in its wavy lines, let us remember the persevering industry that brought it to such perfection.

Bernard Palissy was a Frenchman who made a living by land surveying or painting glasses as occasion demanded. Once he happened to see a white enamelled cup in a certain household, which so much caught his fancy that he decided to discover the secret of its beautiful finish. Utterly ignorant of the material or manufacture of the article of beauty on which all his ambitions were focussed, he set about his self-appointed task like a man groping in the dark. First he mastered the rudiments of peasant pottery. He tried diverse methods of glazing the surface of hfs handiwork. meeting with a successien of dismal failures. He spent all his fortune to buy fuel for his furnace. It is said that sometimes in the glowing enthusiasm of the discoverer he even burned house-hold furniture to feed the fire of his furnace. It was a tragic sight to see his wife and children clamouring for food and trying to divert him from what seemed to them nothing short of madness. Sixteen years he struggled on like this without the least promise on success.

At last Palissy managed to get the patronage of a nobleman, with whose help he was enabled to work in more congenial circumstances. Fortune

began to smile upon the untiring worker; for, gradually his work became known at the court of France. Once royal patronage was secured, Palissy's work went on prosperously. He succeeded in manufacturing pottery superior to anything made in Europe till then. Vases, plates and dishes were turned out of his factory, decorated with realistic figures in subdued colours. Though it is to be admitted that he was not able to discover the secret of the glaze that set him on his bold venture, he succeeded in revolutionizing European pottery.

The great German chemist Ehrlich was very much interested in the search for new chemicals with medicinal properties. Once he was engaged in finding out a specific for the dreadful disease known as syphilis. His experiments indicated that if he could force an arsenic atom into combination with a chain of carbon atoms so as to form a ring, the resulting compound would have the desired medicinal property. He tried several methods of preparing the compound he had in view; but all his efforts were fruitless. Either the arsenic refused to enter into combination, or the resulttng compound was unsuitable for the purpose on hand. Ehrlich, however, was determined to synthesize the right compoud. Six hundred and five times he tried and six hundred and five times he failed, and failed miserably too. He tried yet once again and this time his labours were crowned with success. In honour of this famous discovery the medicine

came to be known as 606, * and syphilitic patients all over the world use this, little knowing the hard labour it cost its discoverer.

Indigo, as everybody knows, is a beautiful blue dye. Till a few decades ago India was the home of the indigo industry. Many a poor peasant lived on the cultivation of the indigo plant. In fact the world depended on India for indigo.

Meanwhile Germany, the cradle of the synthetic dye industry, was attempting to prepare indigo artificially. Her chemists suggested that some of the by-products of the coal-tar industry, which were then being dumped in the market for want of proper use, could be utilized for the synthesis of indigo. The Government raised the battle cry and called her best chemists to the front line. Several laboratories were built and different methods of preparing indigo were devised and tried. Thousands of tons of chemicals were used and millions of pounds had to be spent. But the methods were either failures or they entailed too much expense for commercial success. All the same, the research was pushed forward with unabated enthusiasm. It seemed so ludicrous to the laymen that so much fuss should be made and so much money spent for the preparation of a blue powder. For the German scientists, however, it was a fight to the finish.

After years of unremitting toil, a method was devised for the manufacture of indigo, at a cost far less than that of the natural dye from India. The

* Salvarsan.

German indigo industry soon assumed such proportions as to capture the world market. This gave the death blow to the Indian indigo cultivation; and it was not long before indigo began to be imported into India from Germany.

Sometimes great things have been achieved by men who, owing to certain incidents in their early lives, came across some problem or another the solution of which they took as their life-work. They made all preparations for the supreme task, concentrated all their attention on it, subordinated all their interests to it and were not satisfied till they found out a solution to it. They were not men with any unusual brilliance. Perhaps we should never have heard about them but for their concentration on one superb achievement.

The discovery of the modern method of manufacturing the metal aluminium is an instance in point. C. M Hall, the hero of this discovery, while a boy happened to come across an old book of chemistry used by his father. The book had no cover or title page; all the same, he devoured its contents with eager enthusiasm. He got particularly interested in something he read about aluminium in it. Later on, he come to know that every clay-bank was a veritable mine of aluminium whereas the metal ttself was costlier than silver. His mind was greatly disturbed at such a useful metal being so costly, when potential sources of it were so plentiful. He decided to work up a method of extracting aluminium cheaply from its ores.

The field was new to him and the difficulties were many. He read all the literature connected with the subject and made the necessary preparations. His idea was to invoke the aid of electricity to decompose some of the cheap aluminium minerals. Since solid minerals did not conduct electricity he had to find out minerals or mixtures of minerals which melted easily. To make his batteries he had to chop the wood and fashion the zinc plates himself. But Hall would not swerve from the supreme goal of his life. Working under severe handicaps he developed and perfected a method of producing aluminium, by passing a current of electricity through a molten mixtue of certain aluminium minerals. He achieved what the greatest chemists of his day had longed for in vain. The practical outcome of his discovery was that, what was once a luxury found of the tables of barons became an everyday article in the cottage.

Dr. Schliemann, even while he was a boy, was very much interested in classical literature. Before he was ten years old, he came to the conclusion that the stately walls of Troy could not have disappeared, but might be lying hidden under the dust of centuries. To unearth his ancient city and bring to the light of day its mighty ramparts became the burning passion of his life. Sunk in poverty, as he was, hardly able to keep body and soul together, he found little to encourage him. He set apart, however, as much as he could spare for his self-education, and prepared himself for the

great task he had in view. Slowly he rose in his business and began to acquire wealth. When money began to jingle in his pocket, Schliemann decided that the first charge on his purse should be the much-longed-for excavation.

For a thousand and seven hundred years, scholars had discussed without coming to any conclusion the position of the remains of the ancient city. Schliemann decided to solve the problem by actual spade work. He passed all the earth dug up through a sieve, lest anything of significance be lost sight of. By systematic work he was able to unearth many valuable antiquities; one of his discoveries was a hidden fortress, which he took to be a part of Troy. Schliemann was not able to complete his work; but his successors, working along the lines indicated by him, disclosed the site of Troy. That was the crowning glory of all Schliemann's dreams, struggles and suffering.

Smallpox was one of the most dreadful ministers of death in the seventeenth century. There being no medicine to prevent its irruption or to cure it once it set in, the fell disease took a huge toll of human lives. It exterminated whole populations of towns, and left hideous mark on the faces of the few who did not succumb to it. Look at the conditions now. Smallpox is no more dreaded than measles; and death by smallpox is a rare occurrence. Everybody knows what has brought about this transformation. But few know anything about Jenner, the apostle of vaccination, or how he

happened to discover this amazing means of preventing smallpox.

It was while Jenner was a medical student still in his teens, that the incident occurred which decided for him his great life-work. A milkmaid, who had come to the hospital where Jenner was working, when warned against small-pox, happened to remark, "I cannot take that disease, for I have had cow-pox." This statement aroused the curiosity of the young student and induced him to investigate its truth. When he went to London to continue his studies, he mentioned his big idea to one of the greatest surgeons of the time. The latter encouraged the boy with the words. "Don't think, but try. Be patient, be accurate." The words of the milkmaid and the stimulating advice of the great doctor kept ringing in his ears, till at last he decided to make a scientific study of the subject.

First Jenner proceeded to show conclusively that cow-pox did prevent small-pox. On inquiry, he found that some people who had been attacked by cow-pox were not immune from small-pox. Without being annoyed by this unwelcome information, he studied the cases minutely and showed that there were two kinds of cow-poxes, one of which alone gave immunity from small-pax.

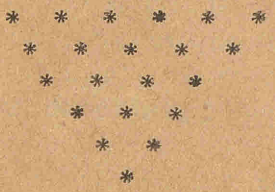
Now the problem that lay before Jenner was to induce the right kind of cow-pox in man, so as to make him immune from small-pox. For this he proposed to extract a serum from pox-stricken cows and inoculate human beings with it. He expected

that this would produce a mild form of cow-pox in man rendering him immune from small-pox. Jenner was venturing into an unknown field; and his difficulties were many. It took him twenty years to put his ideas into practice. Throughout this period, he was constantly experimenting. He tried different methods of preparing the serum, utilizing all his spare time for his research. After a series of failures he was able to prepare a suitable cow-pox vaccine. The first subject to be vaccinated with it was a boy of eight years. Later, the boy was vaccinated with the lymph of small-pox; and Jenner noted with pleasant satistaction that no disease followed.. The remarkable success of the first attempt encouraged him to vaccinate several other children all of whom became immune from small-pox.

This was how Jenner transformed folklore into a scientific means of saving the lives of millions. Gradually the discovery spread throughout England and the Continent. In spite of the opposition which any innovation brings in its wake, it was not long before vaccination was adopted by all the civilized nations of the world. The idea was given to Jenner by others. But to test its validity by experiments and transform it into a practical means of preventing small-pox it required the sustained and painstaking work of a life-time.

How refreshing it should be for those, who toil hard in obscure laboratories without any promise of success, to learn how much hard labour and

persisent effort lie behind the great discoveries in science. The glamour of a thrilling discovery often blinds our eyes to the grim toil behind the scenes. Many an intricate problem given up by investigators might have yielded its clue, if only it had been tried yet once again. The path of persevering industry is often the only way to discovery.



CHAPTER IV

VENTURING INTO THE UNKNOWN.

Far from being a soft sentiment, love of science is the driving force urging her sons to heroic deeds. The spirit of adventure is in the make up of every scientist ; and it has been the secret of many a great achievement. To explore new fields beset with dangers, and to venture into strange and unknown realms have been the constant delight of scientists Many discoveries would have been indefinitely delayed or never made but for the enterprise of some bold soul. No better example could be given of a daring adventure resulting in a momentous achievement than the discovery of America by Christopher Columbus.

The bold proposal put forward by Columbus was to reach the romantic lands of the East by sailing towards tha West. It was not Columbus who discovered that the earth is a sphere, and that so there should be a way to the East by the West. He only dared the risk of testing for himself the truth of what he had learnt from the writings of great scholars. He had read with thrilling interest about the adventures of great sailors. They spoke about driftwood and corpses floating in distand seas, indicating the existence of unknown lands beyond the horizon. No less was he moved by the gorgeous descriptions of romantic cities of the East, of lands glittering with gold, and of the

domains of Kublai Khan, the Khan of Khans, of immense fabulous wealth. Those were days when the Portuguese vessels were pressing forward from discovery to discovery of new lands along the coasts of Africa. But none of them had dared to proceed west-wards. Our hero's blood, however, throbbed in his veins with the desire to venture forth into the unknown seas, to face the perils of the deep, and to show the world that there is a way to the East by the West.

Many a lord and king did he approach for financial help in his project. Having failed in his native land, Italy, he waited upon the King of Portugal and then on the Queen of Spain. Gross was the ignorance and stupid the conservatism that he had to fight against. With the crusading zeal of the age that had gone by and the spirit of scientific discovery of the age that had not yet dawned, Columbus was a man not born for his generation. Royalty and commons alike turned a deaf ear to his speeches. To launch forth on a fanciful expedition and to sail in uncharted seas unfurrowed by any ship seemed midsummer madness to all. Geographic knowledge was but just awakening then. Reports of sailors mingling fact with fiction had conjured up in every mind the horrors of fhe unknown seas. Legends of monsters of the deep jealously guarding their territories, of stagnant seas and fiery skies, of wandering spirits and flying islands, all combined to invest the unknown with the terrors of hell. And what was this

Italian dreamer going to do with the frail wooden vessels and the crude compasses then in use, except depend upon the mercy of winds in the vast expanse of unknown seas? The queen and her advisers would never allow the state coffers to be drained by this visionary. And yet the soul of Columbus yearned for the dangerous enterprise.

After incessant attempts to win over the queen he set sail for France. But later, the queen changed her mind and sent messengers after him to bring him back to Spain. She agreed to his conditions and got ready a few ships equipped and provisioned for a year. At last on the 3rd of August, 1492, Columbus set sail off the coast of Spain.

After many days of voyage the crew began to grumble. Their vessels cut across vast stretches of sea-weed, and the terrified sailors feared that they would run on submerged rocks. The compass needle occasionally showed strange movements which confused the officers of the ships. But Admiral Columbus pacified them with an astronomical explanation of the phenomenon. Now and again they saw indications of land like birds, crabs and grass. Sometimes they thought that they sighted land in the distant horizon, with eventually turned out to be a phantom. The stout-hearted mariners, deceived day by day like this, and growing sick of the sea, conspired against the admiral. They even planned to throw him overboard. But our hero, though he knew that there should be some islands about, would not deviate

from the westerly direction, lest detention in the islands should stand in the way of his achieving the goal of his voyage. He tried to soothe the hostile mariners with soft words, describing to them in glowing terms the glorious prize that awaited them.

At last in the small hours of the morning of the 12th of October, 1492, Columbus saw a few moving lights in the distant horizon and inferred that they were from land. The captains of the various ships headed by Columbus in full armour and followed by the crew landed ashore. Falling upon their knees they poured forth their gratitude to the Almighty. Next in the true whiteman's fashion Columbus took possession of the land on behalf of the Spanish monarch.

Gradually Columbus made friends with the natives of the land, who, thinking that the white men had descended from heaven, treated them with due respect and admiration. Noticing a few gold ornaments on their persons they were asked from where they got the gold. They indicated to him by gestures that further south there was a great king who had much gold. Columbus at once jumped to the conclusion that he was the long-looked-for Kublai Khan of his fond dreams. So he proceeded southwards, and after coming across a number of Islands like the one in which he had first landed, he met the king. Columbus was warmly received and hospitably entertained by the king.

After exploring the islands for some time more, he built a fort and established a colony in one of the islands. Then he set sail for home. On his return journey Columbus met with several mishaps. Some of his assistants proved unfaithful; and twice the Atlantic rose in turbulent storms, the fury lasting for days. To cut a long story short, after a series of thrilling adventures he reached home, and was given a warm reception at the royat court. Columbus had brought with him evidence of the new land he had discovered, including a few Red Indians. No general returning home after a triumphant military campaign ever received greater honour at the hands of his countrymen. He was the hero of the day and those timid conservatives who opposed his schemes, hid their faces in shame.

Christopher Columbus was a scientist before the dawn of the scientific era. Impelled by the desire to know the unknown and to bring to the light of day hidden knowledge, he was prepared to face any danger. May be, the purpose of those who financed his compaign was purely material. But the spirii that stimulated Columbus was noble and the results epoch making.

No less daring was the first attempt to cross the Atlantic in an aeroplane. The Great European War, as nothing else, pushed to the foreground the value of the aeroplane as a means of travelling. Long non-stop flights were unknown in those days; and to cross the Atlantic was the ambition of many an airman. Early in 1919, two pilots, H. Hawker

and M. Grieve, decided to try their luck. It was a distance of about 1800 miles across the fierce Atlantic notorious for its squally weather. Once they started, they would be entirely out of touch with the world and at the mercy ot wind and storm. Hawker and Grieve realized the terrific risk they were running. They knew too well that there was no achievement without risk. Their hearts throbbed with the thrill of conquering the Atlantic through the air. They saw before their eyes the halo of a great achievement in aviation, in whose brilliant blaze their lives shrank into insignificance. They would throw away their petty lives in such a noble cause.

Hawker and Grieve got their aeroplane ready and took off from Newfoundland heading towards England. For a few hours everything went on smoothly, the machine roaring over the Atlantic at more than a hundred miles per hour. Soon their way was obscured by a cloud-bank which became thicker, as the machine cut its way across it. Nothing could be seen even a few inches ahead. The air around was enveloped in a misty darkness. They were already flying about 10,000 feet high; and they dared not get away from the clouds by soaring higher, for fear of running short of petrol. So they descended a few thousand feet and emerged into clear air. But this was not to last long; for soon they faced a thick mountainous cloud, black and forbidding. So they dropped lower still and began to fly only a few hundred feet above the sea.

Meanwhile a very unfortunate catastrophe had befallen their machine. The radiator of their engine got out of order and the water in it began to boil furiously. They knew that if the water got exhausted, the engine would get red hot and collapse. They were flying very low; for rising meant generation of more heat in the engine which would precipitate the crisis. They looked ahead of them and saw the 900 miles separating them from England. They looked down and saw the mighty Atlantic gaping her foamy mouth, as if to swallow them. Then, as luck would have it, the plane gave a sudden dart forward and upward. They escaped thus an immediate drop into the ocean; but they knew that the utmost they could expect of their engine was to work for just about an hour more. So they decided to fly about in search of any passing ship. They flew frantically for some time meeting only floating clouds and angry waves. The fog became denser and a wind was rising. Every second the water in the radiator was boiling away, the engine getting hotter, the plane getting more out of control, and the gallant aviators drawing nearer, as it seemed, to a watery grave.

Suddenly the hull of a ship burst out of the foggy horizon. Hawker shouted for joy. The jubilant aviators made for the steamer, fired three distress signals, and dropped down some distance ahead of the steamer. They detached the boat with which they were equipped and got into it,

leaving their machine to be swallowed by the cruel waves. The steamer had meanwhile launched a life-boat, which, rushing to the scene, picked up the noble pair. As the ship was not equipped with wireless, they had no means of letting an anxious world know about the timely rescue. Many thougt them to have been devoured by the Atlantic; and it was only a week later that the world knew that the valiant aviators were safe. The enthusiasm with which they were received in England was unprecedented. So daring was the venture and so thrilling the escape. Their attempt to cross the Atlantic was a failure, but it served as a firm stepping stone to future success.

The conquest of the Poles has called forth the adventurous spirit of some of the boldest men of science. Party after party has ventured into those perilous region for scientific investigations. One of the saddest stories of geographical exploration is that of the tragic fate of Captain Scott and his companions of the British Antarctic Expedition. The biting cold of the Antarctic regions and the dangers of blizzards were well-known to them. And yet they went all the way from England to explore the icy wastes of the South Pole, to study the forms of life there, and to take certain physical and geographical measurements. It was a heroic march from where the steamer landed them to the South Pole, a distance of 147 miles. Trailing their sledges they cut their way across the impenetrable ice. When at last they reached the South Pole,

on January 18th, 1912, the whole company was exhausted beyond description.

Their physical exhaustion made the return journey all the more perilous. One of the company fell ill and died on the way. The cold was unbearable and walking on ice paralysed their limbs. In spite of so many hardships, they carried on their scientific investigations and collection of biological specimens with unabated zeal. One of the company, being stricken severely with frost-bite and finding that he was a drag on his comrades, decided that he would not retard their progress any more. He told his friends, "I am just going outside, and I may be sometime." It was blowing a terrific blizzard. He went out into the blizzard and his friends saw no more of him. All that they could do for him was to post an epitaph in his honour, "Hereabout lies a very gallant gentleman."

Captain Scott with his remaining two friends proceeded apace. After a few days, they were forced to camp on the way on account of another blizzard. They were confined to their camp longer than they expected. The food supply had run short, nor was there any fuel to keep them warm. The heroic captaim felt the shadow of death closing in upon him. He wrote his last message, placed it in his diary, and leaning against the pole of his tent met his end. The diary which was recovered from the snows a year later contained the following: "We took risks. We knew we took them. Things have come out against us. Therefore we have no

cause for complaint; but bow to the will of Providence, determined to do still our best to the last." The bodies of those heroic souls were engulfed in the Antarctic snows; but their spirit far from being smothered rose victorious enkindling young hearts to adventure and endeavour.

It is the same spirit of adventure that stimulated batch after batch of men to scale the heights of the unapproachable Himalayas. The precipitous ridges, the dizzy heights and the perilous snow, have not baffled those brave souls. They will not give up their efforts, nor will their zeal cool down, till they reach the summit of Mount Everest. When Everest is at last conquered, let us hope Indians will have played a more important role in tt than as coolies and porters.

The United States Air Service was once faced with the problem of a certain kind of aeroplane wing collapsing while flying at high speed. One of the pilots decided to find out the cause of the trouble. He took a machine to a perilous altitude and casting all fear to the winds dived vertically down. As the machine rushed down with ever-increasing velocity, the pilot was coolly making observations of the changes undergone by the fluttering wings. He noted that the disturbance started at the extreme tips of the balancing planes, and gradually spread to the wings till at last the main planes bent and collapsed. Then he jumped from the machine and slowly floated down with his parachute, while the aeroplane rushing at

appalling speed crashed to the ground into a heap of ruins. He knew that he was taking a terrible risk; but he also knew that the valuable information he collected could never have been obtained without such risks.

The history of medical science shows nothing more ennobling and more inspiring than the heroic idealism of the pioneers in the study of contagious diseases. Early in this century yellow fever was the bane of American colonization. During the investigations of the mode ot communication and the conditions of prevalence of the fell disease, it was necessary to test whether the fever was transmitted from person to person by mosquitoes. One of the doctors in the field readily allowed himself to be bitten by a mosquito, which had previously bitten a yellow fever patient. The brave doctor contracted the disease and died a few days hence.

In one of the experiments, to see whether the disease could be transmitted without the agency of mosquitoes, three men had to sleep in an ill-ventilated room night after night, surrounded by furniture and clothing used by yellow fever patients. The three bold men risked their lives in submitting themselves to this experiment; but when the ordeal was over, a definite piece of knowledge was added to the growing science of bacteriology. For, the experiment proved conclusively that yellow fever germs are not transmitted from person to person through articles used by the patient.

In the same year two doctors were despatched from England to study yellow fever in central America. Both knew too well the dangers to which they were exposing themselves. But they pressed on gallantly to the service of science and humanity. Both contracted the disease and one died of it. His death added yet another name to the roll of martyrs in the conquest of yellow fever. It was only by paying such priceless tribute that the cause of the dreadful disease could be found out. The Panama Canal would never have been constructed but for the eradication of the death-dealing mosquito from the land. Lesseps, the hero of the Suez canal, had already made an unsuccessful attempt to cut through the Isthmus of Panama. But his men died of yellow and malarial fever like flies before fire; and Panama came to be called "The Whiteman's Grave." Lesseps had to order an honourable retreat. The little grey gnats had first to be conquered; and for this, the glorious company of the martyrs paved the way.

It is, indeed, very inspiring to watch the glowing interest with which scientists flock around a dangerous phenomenon or a thorny problem. They never turn back from risky experiments. In fact the tougher the problem and the more perilous the research, the larger is the crowd of investigators.

In the eighteenth century, when the science of electricity was still in its infancy, an investigator while trying to store it in a bottle of water, got an

electric shock, which paralysed his arms and shoulders. Before that, nobody was able to accumulate so much electrietty as to give such a dangerous shock. The phenomenon attracted universal atiention. Many scientists came forward to repeat the experiment. One professor went so far as to say that he wished to die of the electric shock, so that the account of his death might furnish a subject for consideration by the French Academy of Sciences.

In the course of his researches into the possibilities of using elecfricity for lighting purposes, Edison discovered that, when electricity was conducted through a carbon filament placed in a vacuum bulb, the filament glowed emitting a brilliant light. The carbon for this purpose was prepared by charring strips of bamboo. Edison sent his men all over the world in search of the most suitable bamboo to be made into filaments. Some explored the sandy forests of Japan; others pierced the thick Amazonian jungles, never before trodden by the feet of man. One of these explores, who had been dispatched to Hanava was seized with yellow fever as soon as he reached his destination; and he succumbed to it. The glorious part of the story is that when the news of his death reached Edison, about a dozen of his assistants came forward offering to take the place of their ill fated comrade.

When the Montgolfier brofhers made their first balloon it was a mere toy. But slowly they

made bigger and bigger ones. When the balloons attained sufficient lifting power to raise heavy objects, the idea of human beings going up in balloons came to be seriously talked of. But the King of France was against any of his snbjects risking his life in such foolhardy adventures. He was of opinion that some criminal might be chosen tor that purpose.

All the same, in many a heart there glowed a warm desire to be the first to achieve that honour. In one gallant soul it burned to feverish heat. F. P. des Roziers was his name. He would not leave the honour of going up in a balloon for the first time to a criminal. He was determined to risk his life for the achievement; and his offer was accepted. It was, indeed, a thrilling experience to be popped up in a balloon thousands of feet up into the air with a live fire underneath which by an unfortunate turn of events might at any moment devour the balloon and the balloonist. But Roziers did not flinch. He undertook the bold enterprise, and earned the glory of being the first to demonstrate the efficiency of the balloon for flying.

The story of the discovery of fluorine stands out as one of the most moving in the history of chemistry. Chemists knew that certain compounds contained that element. Other related elements like chlorine and iodine had already been isolated from their compounds. But the corresponding compounds of fluorine defied all attempts at decomposition. The experiments were fraught with

the utmost danger, by reason of the corrosive and poisonous properties of the chemicals used. More than one chemist lost his life. But there was no dearth of honest soldiers pressing forward and opening hostilities on every front. The problem was solved at last by decomposing certain compounds of fluorine by electricity under special conditions.

Not long after the discovery of X-rays, it was found that they had a very injurious effect on the human skin. This, however, did not prevent the physicists from investigating the properties of X-rays. Many of them had to sacrifice their health at the altar of science and some even their young lives. The research on X-rays, however, proceeded apace, till that wonderful radiation became a beneficial instrument of healing in the hands of the physician, and an invaluable agent in the solving of many problems in science.

The spirit of adventure pervades every scientific investigation. Every research is an essay into the unknown, and every scientist a Columbus sailing in uncharted seas. When a man of science undertakes a piece of research, he is investing money, time and energy, on what may culminate in failure and loss. Timid men shudder to take the risk and turn back; but the true sons of science go ahead. When the German Government invested millions of pounds on the manufacture of indigo, they were taking their chances. When Madame Curie decided to fish out the few grains of the

unknown metal radium from tons of rocky minerals, she was staking everything on a possibility. Jenner was venturing into an unknown field, when he attempted to prevent small-pox by cow-pox on the word of a milkmaid. No man without the spirit of adventure in him ever achieved anything great.

There is a very edifying story in Greek mytho. logy, according to which two men attempted to fly with the aid of artificial wings fixed to their bodies with wax. One of them flew low and landed safely. The other intending to test the soundness of his apparatus still further, soared high into the upper air. The heat of the sun melted the wax and the wings fell off, fhe daring avaitor dropping down discomfited. Though his adventure ended in failure, it served to show the world the limited utility of his flying contrivance. The former too timid to try any experiment sought the path of safety and made a succesful flight. But it is the other one who has earned a place in the realm of science.

CHAPTER V

GEMS OF TRUTH FROM COMMON THINGS.

The earliest inventions of man were, probably mere imitations of Nature. Primitive men, especially the more reflective of the lot, would have watched with interest various natural phenomena and attempted to reproduce them. Walking upon the soft mud left by a recently flooded river, the primitive man watches the depressions caused by his feet. The mud gets baked up in the sun, leaving the foot-prints permanently stamped in it. Then one day there is a heavy shower, and our friend observes that all the depressions have been filled with water. Nature has fashioned out of the mud vessels which will hold water. The instinct of imitation, so strong in the primitive man now comes into play. He takes some soft clay and moulds it with his hands, in the shape of the shells of fruits which have till now served him as cups. He dries it in the sun and pours water into it, and feels extremely satisfied with his handiwork. That was, probably, how man made a pot of clay for the first time, and laid the foundation of the pottery industry.

Take again the discovery of fire. Man must have observed the dry branches of trees catching fire when they rubbed against each other in the wind. He also might have noticed the heating effect of a forest fire. On cold wintry nights when

he was shivering all over, it would have occurred to him to imitate Nature by producing fire from dry sticks. Here was the origin of the family hearth.

The ancient man ate his food raw whether of animal or vegetable origins. Then how was he introduced to the luxury of cooked food? More likely than not, Nature offered him the first cooked dish. Very often forests caught fire, and man, while inspecting the ruins of the conflagration, would have noticed here and there carcasses of animals that had perished in the fire. He would have found the roasted meat more to his taste than anything he had eaten till then. Since then when ever he brought home any venison, it was handed over to the woman to be roasted in fire. A new department was thus opened in his cave, namely the primitive kitchen. Incidentally it may be mentioned, that it was the kitchen that differentiated the functions of man and woman. Till then, except in tne matter of rearing the young, there was little difference between the activities of the two sexes. The discovery of cooking tied down woman to the kitchen and shut her out from outdoor activities.

The most primitive man had, probably, only sticks and stones with which to hunt animals for his food. He would often have hurt his feet by thorns and sharp stones during his escapodes (3). It might have occurred to him on such occasions, that if the end of a stick were sharpened to a point as in a thorn it would give him a more effective

(3) mischievous adventure.

weapon. This idea when put into practicc provided him with a wooden spear. Again, it must have been a flat stone sharpened at the edges that gave him the first knife.

Instances may be multiplied, but enough has been said to show how primitive man, though blessed with no high order of intelligence, was able to invent things by merely observing Nature and imitating her work. Even after the advent of civilization, observation and study of apparently common-place phenomena have led on to several discoveries.

In ancient days the city of Alexandria was a centre of learning. One of the scholars of the university was in the habit of sailing up the Nile. He noticed that as he sailed towards the south, new stras came into his view from the southern horizon, while the northern stars disappeared one by one. He turned over in his mind the cause of this remarkable observation. It struck him that if the earth was a globe, he would be able to see more of the southern sky and less of the northern, the more he travelled to the south. Thus it furnished him with a proof of the rotundity of the earth, which was a much-discussed question of the day.

J. Priestley, an English priest, used to watch the frothing gas produced by the fermentation of liquor in a brewery near his house. Being inquisiiive to know the nature of the gas he collected some of it and passed it through water. On tasting the water, it was found to have taken a delicious flavour. He

drank large quantities of the water and felt a feeling of exhilaration. Priestly had prepared the first aerated water. He showed that a solution of the gas produced by fermenation and which we call now carbon dioxide is a pleasant beverage. Next time we drink a glass of aerated water, let us remember the English clergyman who taught us how to make one.

J Clayton, another English clergyman happened to notice one day an inflammable gas escaping from a coal seam. Curiosity led him to try wheather he could get the gas by heating coal. He heated some in a tube and got an inflammable gas burning with a luminous flame. This was how coal gas came to be discovered. Till then even big cities like London and Paris weare lit only by dingy oil lamps. The discovery of coal-gas provided man with a convenient means of lighting towns. Big factories for manufacturing the gas were started, nd city after city began to be illuminated by the gas. The scarching observation of a clergyman was that laid the foundation of the industry.

The great Italian physicist, Galileo, while he was a student at the University of Pisa, was attending divine service one morning at the cathedral. His attention was diverted to a pendant lamp swinging majestically above his head. He observed a regularity in its movements which struck him as very remarkable. Though the oscillations were gradually dying down, the lamp seemed to swing as frequently as ever. He had no watch

with him; or rather watches were unknown in those days. So he felt his pulse and satisfied himself that the time of an oscillation remained constant, even though the lamp was swinging over decreasing ranges. This was how Galileo discovered the principle of the pendulum, the time regulator of clocks. The pendulum ol a clock would oscillate with the same frequency wheather it is swung over wide or narrow ranges thus enabling the clock to run with a constant speed. Many men had seen swinging bodies before Galileo, but Galileo ssw something more than what met his eyes, because he looked at the phenomenon with the eyes of a kneen inquirer.

Towards the end of the eighteenth century one evening, two Frenchmen, while warming themselves by the hearth, noticed how small bits of paper let loose above the fire rose up quickly and lost themselves in the chimney. Their interest being roused by this observation, they proceeded to make paper bags with holes at the bottom and hold them above the fire, till on release the bags rose up with astonishing rapidity. Soon they made large paper balloons and filled them with hot air. On being released, they shot up into the air to the delight and wonder of the onlookers. When they found that after a time the balloons came down, because the hot air inside had become cold, they hit upon the idea of keeping a dish of charcoal burning underneath the balloon. This ahd the desired effect and kept the baloon floating

in the air for quite a long time The Montgolfier brothers, for that was their name, fully conscious of the significance of their discovery attempted to make bigger and bigger balloons, till at last they gave a public demonstration with a balloon which rose into the air as high as a mile.

While inspecting an armament factory; Count Rumford, an ex-army officer, happened to notice the enormous amount of heat produced during the boring of cannon. This observation led him to reflect on the nature of heat. The current view was that heat was a material fluid existing in all substance to a greater or less extent. The possibility of generating an indefinite quanitity of heat from material bodies, without the body being used up in any way suggested to the count that heat could not be a material fluid. The boring tool, the cannon and the metal filings, togethnr did not suffer any loss of weight, though they generated so much heat. By firmly pressing a borer on a block of brass with great force and rotating the latter rapidly, Rumford could produce enough heat to boil the water in which the whole apparatus was immersed. If heat were a material fluid, there should certainly be a limit to the amount of heat that could be generated from a body. But the supply of heat appeared to be inexhaustible. Hence Rumford suggested that it was the friction of one block of metal against another that produced the heat. The friction caused the molecules of the metal to move about with greater velocity, and

the hot metal differed from the cold one, only in having its molecules in a state of more violent motion. Heat, in other words, should be a form of energy and could not be a material fluid. The soldier-scientist had done a signal service to the progress of physics by bringing to light the real nature of heat.

One fine morning in 1842, Roget, a physician by profession, looked out through his window and saw a baker's cart rattling along the street. He noticed to his surprise that, though the cart was moving along, the spokes of its wheel appeared to be stationary. He was very much puzzled at this strange phenomenon, and proceeded to investigate its cause Probably many before him had seen similar phenomena, but they had passed them over and never cared to reflect on them. Roget, however, would think out an explanation.

Roget's window was of the Venetian type with gaps between the blinds. He remembered how, while looking out through the window, he happened to move his head up and down. Hence he must have seen the cart through different gaps one after another, the vision being cut off by the blinds at intervals. Since the wheels were roatating the spokes of the wheels would be going round and round But it so happened that by the time he began to look through the second gap, thh spokes had turned round sufficiently for each spoke to occupy just the position which the spoke in front of it occupied while he was looking

through the first gap. As the spokes were al similar, the picture of the wheel as viewed through the second gap was the same as the picture got through the first gap, though the wheel was turning round. That was why the spokes of the wheel asseen through the several gaps in quick succession seemed to be stationary.

Now it remained to explain why he was able to see the cart continuously, though his view was intermittently cut off by the blinds one after another It is a well-known fact that when a man waves his hands rapidly, he can see it at different posittons at the same time. In fact instead of seeing the hand, he sees only a hazy hand. This is because anything that we see is retained in our eyes for one-tenth of a second. When we see any moving object, we are actually seeing it not only at the position it is now but at all the positions it occupied during the last one-tenth of a second seeing it Roget was able to see the cart even when his view was cut off by the blind, because the time during which the sight was thus cut off was less than one-tenth of a second.

It was by making use of these principles that the cinematograph was invented. A series of pictures, showing the various stages of any object in motion, is thrown on the screen at the rate of about sixteen pictures per second. Though the object in each picture is really stationary, since it is seen each time at a new position, the illusion of movement is created; and owing to persistence of

vision for one-tenth of a second the pictures are seen continuously. Imagine, for example, that we are seeing on the screen the picture of a man raising his hand. In the first picture the man's hand is hanging down, in the next slightly raised, in the next a little more, and so on. Because these pictures are thrown on the screen in quick succession, it appears as if the man is raising his hand. Though during the intervals between two successive pictures the screen is not illuminated at all, there is always at least one picture in our eyes owing to persistence of vision. Each picture merges into the one which preceded it, and thus we are able to see the pictures continuously. This is how the principles, first brought to light by Roget, are made use of in cinematography. What a wonderful culmination to an apparently commonplace observation!

Nature is always inviting us to probe into her mysteries. She whispers to us in ever so low tones vague indications of her secrets. The keen inquirer at once takes the hint, investigates the phenomenon, and discovers the truth. What is too commonplace to the layman is full of meaning to the searching eyes of the scientist. Every phenomenon in Nature is a signpost pointing towards the portals of a mine of scientific truth. He who can find "tongues in trees, books in running brooks, and sermons in stones" is on the highway to discovery.

CHAPTER VI

CLOUDS THAT BLUR THE VISION OF TRUTH.

No more faithful devotee at the altar of truth could be thought of than a scientist. He is an accurate observer, a faithful recorder and a dispassionate judge. For him a thing is either true or false ; for he knows no half truth. Nor does he attempt to bring about an understanding between truth and falsehood. When he is not sure of a thing he confesses it. An advocate who holds a brief may suppress facts, and exaggerate insignificant details to win his case ; and a politician may compromise with falsehood in the interests of his party. In the realm of science, however, there is no party to be partial to ; nor have its ministers any interest to serve by twisting facts. What does the scientist gain, for example, by saying that the whale is a fish, when his observations show it to be a mammal, in spite of all its aquatic habits ? He merely observes what he sees and pronounces a dispassionate judgement.

Yet in the history of science there have been instances of leaders who swerved from the path of truth. Not that they were insincere to their calling, but their vision was clouded by ever so subtle forms of the spirit of untruth. Sometimes they were carried away by the charm of imagination or by the rigour of logical reasoning. Not very infrequently they failed to recognize truth owing to

the implicit faith they had in their own theories and pet ways of thinking. Occasionally they have been scared away from the path of truth by the power of authority or the unkindly criticism of comrades. One whose vision of truth is not obscured by such clouds is on the highway to make discoveries.

The wise men of ancient Greece were keen investigators of truth. But there was one flaw in their methods of attaining truth. Whatever could be arrived at by correct logical argument from known data was alone regarded as truth by them. Truth, according to them, was not what man perceived with his senses but what he conceived by thinking. The story is told of how in an assembly of Greek sages, a controversy arose about the number of the teeth of a horse. In the heat of the discussion one of them suggested that a horse might be brought there and its teeth counted. But the others rebuked him severly for suggesting such an indecent procedure when the problem could be solved by logical reasoning. The Greek philosophers were drifting away from truth in seeking to reach it by logic alone. For the scientist, however, there is no higher court of appeal than the evidence of his senses.

The last among the great Greek thinkers was Aristotle. He collected, enlarged and classified all the Greek contribution to the knowledge of the physical world, and laid them down for the benefit of succeeding generations. Aristotle wielded a

remarkable influence over the whole of cultured Europe. He held in thrall the minds of thinking men for nearly two millenniums. Aristotle was studied in cloisters and universities, and referred to as the infallible authority on all occasions of dispute. The servile spirit of those dark ages is borne out by the controversy that raged in the ancient University of Pisa, about the time taken by two bodies of unequal weight to fall down the same distance. Aristotle had taught that if two balls, one a hundred pounds and the other one pound in weight, were dropped from a height. the former would reach the ground a hundred times quicker than the latter. For about two thousand years scholars believed in the statement with religious conviction, and handed down the precious knowledge from generation to generation. The faith in Aristotle was so implicit that nobody dared take two stones and drop them down to see whether the great philosopher was right.

But now, Galileo, the young professor of mathematics in the University of Pisa, challenged the validity of Aristotle's statement. In the eyes of the university fathers it was nothing short of profanation to question the great philosopher's doctrines. But Galileo would show by demonstration that Aristotle was wrong. It was a fine morning in Pisa about the year 1591. The university men had assembled at the foot of the famous leaning tower. The superb marble structure shone in the morning sun. A young professor

could be seen on the gallery at the top, balancing two balls one a hundred times heavier than the other. The balls were released simultaneously, and peering eyes saw the balls falling together and striking the ground at the same moment.

The university fathers frowned, and turned the leaves of their books to reassure themselves, that Aristotle had actually stated that a body weighing a hundred pounds would fall hundred times quicker than one weighing a single pound. "This meddlesome man Galileo must be supprssed", was the universal verdict on the daring professor. The wise men of Pisa would rather be untrue to the evidence of their senses, than disturb their intellectual contentment by doubting Aristotle. Respect for authority deafened their ears to the still small voice of truth.

Galileo was a pioneer in the domain of physics and astronomy. He discovered new planets by scrutinizing the heavens with a telescope of his own make. He also observed for the first time dark spots in the sun. The following letter written by Galileo to Kepler shows how minds steeped in Aristotelian doctrines received his discoveries: "Oh, my dear kepler, how I wish that we could have one hearty lauuh together! Here at Padua is the principal professor of philosophy, whom I have repeatedly and urgently requested to look at the moon and planets through my glass, which he pertinaciously refuses to do. Why are you not here? What shouts ot laughter we should have

at this glorious folly! And to hear the professor of philosophy at Pisa labouring before the Grand Duke with logical arguments, as if with magical incantations to charm the new planets out of the sky."

An inquisitive monk plucked up enough courage to scrutinize the heavens with a telescope. He wrote to the superior of his order that he had verified Galileo's observations. His superior replied: "I have searched through Aristotle and can find nothing of the kind mentioned. Be assured, therefore, that it is a deception of your senses or of your glasses." So woefully had Aristotle enslaved the minds of men. No wonder it has been said, "Aristotle has been one of the misfortunes of mankind." *

Imagination is a powerful instrument for probing into the mysteries of Nature. Often facts as they are observed appear disconnected and confusing. But a glow of imagination may light the whole field, revealing the inner harmony of things. All the same, imagination is no more than a hand-maid to scientific investigation. When the scientist dwells too long in the blaze of its lustre, he is likely to be led astray from the path of truth.

Everybody knows that when a metal is heated in air it is converted into an ash-like powder. We know now that this is due to the metal combining

* This remark made by Bertrand Russell applies only to scientific progress. The constributions of Aristotle to other branches of knowledge like logic, philosophy, civics etc. are of abiding value.

and forming a compound with oxygen, one of the components of air. But in the seventeenth century they did not know what air was, and far less what its components were. So the idea that air might be the cause of the phenomenon did not strike them at all. While witnessing the transformation of the bright lustrous metal into a dull ash, the idea suggested itself to their imagination that the change was due to the expulsion of the spirit of burning from the metal. The spirit was responsible for the sheen and lustre of the metal, and when deprived of the spirit of the metal looked dull and lifeless.

They could not, however, devise any experiment to prove the existence of the spirit of burning. Nobody had seen or handled it. Certain facts seemed even to throw doubt on the soundness of the idea. An obvious difficulty was that the ash weighed more than the metal, in spite of its having lost something. This seemed to strike at the very root of the theory. But the supporters of the theory would not allow such a beautiful conception to be torn to pieces so easily as that. They at once came forward with the explanation that the spirit had negative weight, so that its indwelling in any material body would make it lighter and not heavier. The wonder is not that the imagination of some chemists could run riot to this ludicrous[2] extent, but that this foolish theory held away for more than a century. Imagination of this kind unsupported by facts clogs the wheels of scienific progress.

2. Laughable.

When an ingenious explanation for some phenomenon of Nature is discovered, it is likely to lead one to think that the depths of the ocean of truth have been sounded. Such an attitude on the part of scientists arrests further research and causes stagnation. They forget here that truth untolds itslef in endless layers. They are like climbers of the Alps, who get so fascinated by the beauty of a rest-house on the way, where they stepped in to spend the night, that they feel inclined to proceed no further.

J. Dalton, an English school master, formulated a theory about the structure of matter. According to him all matter is made up of extremely minute particles called atoms, each element having its own kind of atoms. Though the atoms are so small as to be invisible even under the microscope, they are the bricks out of which Nature has built up all the diverse kinds of matter. The theory of atoms afforded a lucid explanation of many chemical phenomena. It was hailed as a great boon to the chemical world. No sportsman bringing home his maiden trophy was prouder than Dalton.

Uufortunately, however, Dalton's glory was not long-lived. For soon the Atomic Theory fell on evil days. * A certain scientist discovered a law dealing with chemical reactions between gases. The new law was unexpected by Dalton and was entirely foreign to his scheme of things. In fact some of the conclusions derived from the law were

* Gay-Lussac's law of combining volumes.

contradictory to the Atomic Theory. The acceptance of the law, therefore, meant the overthrow of the beautiful edifice built up by Dalton. Hence he refused to believe in the new law. Basking in the sunshine of his own theory, he was blind to any new light inconsistent with his favourite scheme.

In point of fact, Dalton's theory though brilliantly conceived had a serious defect in it. That was why it clashed with the new discovery mentionod, and created confusion. Later on the whole issue was cleared up by another scientist, * who kept his mind open to Dalton's theory as well as to the new law. He found just in this law, which threatened to demolish the Atomic Theory, the solution of the apparent disparity between the two. By pursuing the implications of the new law it became clear that atoms are not the only particles to be reckoned with. There are other coins too in Nature's currency. For, the atoms as a rule do not exist free, but join together and form bigger particles called molecules. So any theory about the structure of matter should take into account both atoms and molecules. With this addition to the Atomic Theory it no longer contradicted any known fact. Since Dalton did not make any provision for the existence of molecules, his theory was incomplete. And the idea which completed it was afforded by the very law which Dalton refused to recognize. Seeing but the corner of a peninsula he thought

* Avogadro, the Italian physicist.

he saw the whole continent. If Dalton had kept a more open mind to new facts, whether in line with his theory or not, he could have nursed his own child to maturity. But as it happened, he had to leave it to others to establish the idea of atoms as a sound scientific theory. Truth never breaks open into the stagnant reserves of a closed mind.

As an example of an investigator who always kept an open mind to the facts of Nature, Charles Darwin is second to none. He had his own views about how things would turn out in his garden; and he used to predict the results of his experiments to a favourite gardener of his. But when he visited the greenhouse, he found very often that his animals and plants did not conform to his expectations, and his gardener used to enjoy a hearty laughter behind his master's back. The great naturalist, however, was not upset by such experiences. Very often it was from such apparent discrepancies that new lines of research suggested themselves. He faced facts as they were and modified his own theories in the light of those facts, instead of trying to twist facts to suit his theories. The readiness with which a scientist gives up a disproved idea is as admirable as the tenacity with which he holds on to it as long as facts support it. An eye for things not in line with one's views is a virtue in a discoverer.

Sometimes a scientist feels so confidently secure in one view of a problem that other possibilities are not taken into consideration. A certain

investigator happened to get a brown liquid on treating a certain kind of saline water with chlorine. Being unable to identify the brown substance, he forwarded it to the great German chemist Liebig. Liebig thought that it could only be a compound of chlorine, and did not think it worth while to waste his time on it. A few years later, a French chemist got the same brown liquid under similar circumstances. He examined it exhaustively and came to the conclusion that it was the solution in water of a new element, and called it bromine. On entering his laboratory the next day, Liebig saw the brown liquid which he had put away in a corner and heaved a sigh of despair. He had almost come to the verge of discovering a new element; but his prejudice led him away from the path of discovery.

Not very infrequently, when the methods of performing an experiment are improved, and finer instruments are made use of, the results may turn out to be different from those obtained till then. If the new results contradict any well-established principle, while the old ones fitted in nicely with every known fact, the temptation will be too strong for an investigator to hush up the differences, especially if they happen to be small. The faithful devotee of truth, however, will repeat the experiments again and again with scrupulous care to see whether the long-established conclusions are really correct, and if so why the more refined experiments gave results different from the former

Lord Rayleigh, an English physicist, had, in the course of certain investigations, to determine the density of nitrogen obtained from different sources. He noticed that nitrogen, prepared from air by removing the oxygen, showed a slightly higher density than the same gas got by decomposing its compounds.

It is a well-known fact that the same substance always shows the same properties however or wherever obtained. That nitrogen seemed to flout this law was rather disquieting. The differences in the densities were so minute that to the layman it would have appeared extremely foolish to make a fuss over such trifles. Rayleigh could have just ignorad the differences and proceeded to more interesting work. It must, indeed, have been very tempting to him to remain satisfied with the comfortable belief, that it was impossible for the density of nitrogen to vary from sample to sample, and that the differences which he observed were due to experimental error. But his sense of truth did not permit him to ignore a fact which lay so clear before his eyes. He felt that there was something wrong somewhere and proceeded to find out the cause. The density determinations were repeated with scrupulous care. All possible impurities and the whole of the oxygen contained in the air were carefully removed to ensure the purity of the nitrogen. Nevertheless the difference in density persisted.

Soon the suspicion arose that atmospheric

nitrogen might contain mixed up with it another gas heavier than itself and responsible for the whole mischief. Methods were devised with the help of chemists to remove all the nitrogen from a sample to see whether anything was left over. The expectation turned out to be true. A small residue was obtained, which could not under any circumstances be absorbed by the metal used to remove the nitrogen. In fact it would not combine with any of the substances that chemists threw in as a bait. The gas behaved as an unknown intruder from a strange land, who would not supply any key to his identity. Chemists had never come across such stupid inertness. The only thing they could do was to declare it a new element, and call it argon, meaning lazy. Such was the famous discovery of the element argon.

What a romantic culmination to the dull density determinations of a physicist! Reyleigh was responsive to the low whispers of Nature, though they were so annoying that a less wary investigator would have got irritated with them. But he saw in those irksome facts the potential discovery of a new element, and a very useful element at that. For, argon is now used in enormous quantities to fill electric lamps. If Rayleigh had ignored the minute differences in the density of nitrogen which worried him so much, and passed on to more interesting experiments, probably, argon would have lain hidden in the atmosphere for many more years. The path of truth may seem annoyingly

confusing at times, but the sincere worker, who faces all facts trifling or not, always reaches the goal.

When a new discovery is made, it requires firm grit and sustained effort to steer it clear of the rocks and reefs of criticism. Sometimes all the workers in that branch of science may rise in revolt against the new revelation. The discoverer may be attacked mercilessly and criticized virulently. If he is not a true child of science, the sting of criticism and the pangs of dejection will loosen his hold on Truth, and she will quietly give him the slip.

The chemist calls a simple substance out of which no simpler substances can be got an element. Oxygen, nitrogen, sulphur, are all elements. All scientists believe that matter is made up of extremely minute particles called atoms. Each element has its own kind ot atoms, different in weight and other properties from the atoms of other elements. An English chemist called Newlands found out that, when elements were arranged in the order of the weights of their atoms, every successive eighth element was very much of a repetition of the first. In other words, he showed that, if the elements were arranged in horizontal rows of seven in the ascending order of the weights of their atoms, the elements falling into the same vertical group, for example, the first elements of all the rows, resembled each other in many of their properties, as if they belonged to the same family. This was

remarkably interesting; for, chemists had no reason to expect any such regularity. Believing that it was too real to be accidental, he expressed it in the form of a law and made up his mind to publish it.

When, however, the young chemist presented his new idea to the London Chemical Society, poor Newlands was laughed at mercilessly. When one of the members of that august body put the question to the disappointed discoverer, whether it occurred to him at any time to arrange the elements according to their initial letters, the whole house burst into uproarious laughter. The society room rocked with their revelry, and people in the street looked up wondering what had happened to dispel the customary solemnity of those wise men. The unanimous opinion of the house was that, in the best interests of science, Newland's paper dealing with his fantastic idea might be given a place in the waste-paper basket.

Mortified at the hostile reception given to his discovery, Newlands did not proceed further. But later history showed that Newlands had discovered the rudiments of a principle of paramount importance in chemistry. So far as the light elements were concerned, his law seemed to work smoothly. But when heavier elements were included discordant notes were struck. The law, as given by Newlands, evidently did not fit in with all the facts. It had to be modified. Newlands, however, was so deeply disappointed that he did not feel inclined to pursue the subject further;

he had been cowed down by opposition. Twenty-one years later, Mendeleeff, a Russian chemist, made the neceesary modifications and produced what he called the Periodic Table. The Periodic Table is a chart, showing the family relationships of elements. It is known as Mendeleeff's Periodic Table. Nobody calls it Newland's table, though it was he who conceived the idea first. The opposition from his comrades blinded his eyes to the steady gaze at truth, and shattered all his chances of being immortalized in the annals of chemistry as the discoverer of an important law.

Now let us hear the story of a great man, who, though ridiculed and laughed at, remained so firm in his convictions that ultimately he won over many of his critics to his side. It is a matter of common knowledge that some plants like the sensitive plant are very responsive to external stimuli. When touched, their branches droop down and the small leaflets close upon themselves. European physiologists explained this phenomenon as a mere mechanical reaction. But the careful experiments of Sir J. C. Bose, conducted in Calcutta, showed clearly that the movements of plant organs are exactly similar to muscular movements in animals, being caused and controlled by nervous impulses.

In 1901 Professor Bose was given an opportunity to address the Royal Society of London. He showed with adequate proofs and experimental demonstrations, how plants respond to various

kinds of stimuli like touch, heat and poison, and how closely all these resemble animal behaviour. His speech fell on deaf ears. The professor, who was the authority on plant physiology in England, wound up his remarks saying: "It is a pity Professor Bose left his researches in physics and took a field, which may well be left to physiologists. Professor Bose's claims are absolutely impossible. I have tried to detect some evidence for a nervous system in plants for many years past, but never could obtain any." Dr. Bose's work and papers were rejected by the Royal Society; and he returned to India a sadder man, but stouter of heart.

The ruthless verdict of the premier scientific society of the British Empire did not crush the spirit of the great Indian scientist. He got back into his laboratory and repeated his experiments. The contractions and expansions of plant cells, magnified hundreds of times by better apparatus and finer instruments than before, told their tale unmistakably. The throbbings of those minute cells seemed to him as real as his own pulse. When a poison was injected into the plant, the pulsations became weaker and weaker and finally died out. His wonderful instruments revealed the inner secrets of plant life, proclaiming loudly their close similarity to animal functions. Nobody could overlook such clear evidence. He would once again go to England and fight out the cause of truth. And go he did. His opponents tried to place all sorts of difficulties in his way. But slowly men of science

were convinced that there was much truth in the claims of the Indian scientist. In 1915 he made a world tour and lectured in all the cultural centres of Europe and America. Wherever he went he was warmly received. Scientists were astonished at the ingenuity and sensitivity of his instruments. "Where did you get them made?" they asked him. "In India", replied Dr. Bose with patriotic pride.

The European physiologists had made a clear distinction between the mechanisms of plant and animal activities. Whereas animal functions are all stimulated and controlled by nerves, plants were supposed to possess no such controlling agency, all their activities being explained on purely mechanical principles. Sir J. C. Bose tried to bridge the gulf between the two kingdoms, by showing the essential oneness of all life. It was such a wonderfully novel idea, that the scientific world refused to accept it at first. It required the firm conviction and steadfast devotion to truth of a Bose to save it from being thrown on the scrap-heap of science. It cannot yet be said that his claims are universally accepted. But he pursued his reserch untill his death trying by ever so refined methods to establish that plants have really a nervous system.

Truth sometimes crosses the path of her devotee in the guise of an unwelcome guest or a distitute in the gutter. The unwary investigator passes her by, and she calls after him with a pathetic smile, "Ah, don't you

recoginze me?" Truth is strange and elusive. To make out her still small voice requires the humble and open mind of a scientist. Sometimes a shrewd investigator may recognize her all right; but dispirited by doubts and dreading opposition from others, he hesitates to pay his attentions to her. And Truth, slighted and disowned, slowly slips away in search of more confident wooers.

CHAPTER VII

BRINGING ORDER INTO CHAOS.

Though he was impressed with many natural phenomena, and able to make use of some of them for his own needs, the primitive man did not, however, perceive any relationship connecting them together. It was at a later stage in the progress of civilization, that man began to correlate the various facts of his observation. At first man did not know, for example, the connection between flowers and fruits. Later on, the close observation of flowers in the various stages of budding, blooming and withering, and the gradual enlarging of the ovary, showed to his reasoning faculties that it is a flower that develops into a fruit.

Not more than three centuries ago, even learned men entertained absurd notions regarding the life-history of an insect. The evolution of the pupa into the butterfly was looked upon as a transformation, no less miraculous than some of the events narrated in fairy tales. Swammerdam, the French naturalist, closely observed the various changes undergone by the larvae and the pupae. He connected the various facts of his observation and traced the life-history of the insect from the egg to the butterfly. The practical consequences of the discovery have been far-reaching. Insect pests are a curse to the farmer. They are also carriers of the germs of deadly

diseases. In devising methods for the extermination of these baneful insects, a knowledge of their life-history and habits was essential. Thus Swammerdam's labours have been of the utmost value in the campaign against the insect enemies of mankind.

Another intricate problem, about which colossal ignorance prevailed, and which was solved by patient observation and careful reasoning, was the beehive. According to Aristotle, a king-bee was the governor of the hive. It was a country parson that first thought of going to Nature and observing things for himself, instead of blindly believing in ancient lore. Patient observation showed that the head of the beehive was a female. It was Swammerdam who first gave a comprehensive account of the inhabitants of this insect colony, their habits and life-history. The only individual capable of laying eggs in the hive was the queen. The idle drones were found to be males. The worker bees who went about collecting honey and pollen were incapable of laying eggs, though they were not males. Later on, it was discovered by closer observation that the workers were really females imperfectly developed.

By closely watching the emergence of the queen from the hive, her pursuit by the drones, and her final return after a few days to her native hive, it became clear that the object of the royal flight was matrimonial. It was also observed that the queen was fertilized only once in her life, and that it enabled her to lay thousands of eggs.

Another interesting fact revealed to the scientist's observation was that the queen could lay eggs even without being fertilized. The unfertilized eggs were found to give rise to drones, and the fertilized ones to queens and workers. The difference in appearance between the last two was attributed to the special diet on which the future queens were fed, while still young.

Careful examination of the habits of bees has also disclosed the social economy of the colony. The future queen is fed on a special kind of food in keeping with her royal status. The workers go far and wide in search of honey and pollen. They do not grudge the languorous luxury of the drones, who are such a drain on their foodstores. But this generosity does not last long. When the drones have served their sole function in the colony, and food becomes scarce, they are driven away from the hive, the poor drones resigning themselves to their fate in good grace. Every activity in the hive is designed to increase the prosperity of the colony and ensure the continuation of the race. Individuals suffer vicariously for the common good.

Thus by the careful sifting of facts and connecting them in logical sequence, a confused mass of ignorance and folklore has been transformed into a scientific piece of knowledge. It is the revelation of the secrets of the beehive that placed the bee-keeping industry, which is so much talked about now in connection with village reconstruction, on a scientific basis.

The course of the blood stream in the human body has engaged the attention of thinkers from ancient days. Aristotle had taught that blood was manufactured in the liver from where it was carried to the heart and then to the lungs, and finally absorbed by the body. Later workers had developed all sorts of queer notions regarding the subject. William Harvey, a celebrated English physician, had many occasions to observe the arrangement of the blood-vessels in the body. Having realized the absurdity of the views then current, he determined to solve the mystery for himself.

He made a thorough investigation of the heart and blood-vessels of many animals. Frogs, fishes, pigs and dogs were dissected and their viscera laid open on his table. Doctors knew before his time that blood flowed from the heart through the arteries into the body; but they were not aware of a return of the blood to the heart. As Harvey stood watching the enormous quantity of blood gushing out of the heart through the great arteries, the conviction came irresistibly to him that unless the blood is returned to the heart the latter would be emptied of all its contents in no time. He not only observed things as they were, but performed suitable experiments to obtain other related facts. By blocking the blood-vessels by ligature at different places and noting which side the blood vessels swelled, he inferred the direction of the flow. When a vein was blocked, the side nearer to the

heart collapsed; while the other side swelled up, evidently, owing to the accumulation of blood. It clearly indicated that in the veins the blood flowed towards the heart.

Harvey could now definitely state that blood was conveyed from the heart by a big artery, which, by repeated division and subdivision, supplied every tissue of the body with the life-giving fluid. The big vein leading to the heart was formed by the union of smaller ones, which collected the blood from the tissues. How exactly the blood passed from the small arteries to the small veins was beyond his observation. Instead of asserting his own views where his observations failed him, Harvey, like a true scientist, left it as an open question. He suggested, however, that the blood might reach the small veins from the small arteries by percolation, just as rain-water percolates the earth and then emerges in fountains, ultimately forming streams and rivers. This problem had to await the discovery of a powerful microscope for its secrets to be revealed. Now anybody can see how the gulf between the small arteries and the small veins is bridged over by minute capillary tubes, if he examines the web of a frog's foot under the microscope.

It was known for a long time that the heart is divided into two parts by a septum, and that the blood coursing through the left side is distinctly different from that through the right side. In fact the prevalent notion was that the fluid in the felt

half of the heart and the arteries was a sort of spirit and not real blood. The two kinds of fluids were supposed to get mixed up in the heart through the septum, which was believed to be porous. Harvey examined the septum carefully and found it to be non-porous. He showed that the blood carried into the right half of the heart, is expellde through a special artery into the lungs, from where the blood is collected again by means of veins; and discharged into the left half of the heart. It is during its migration through the lungs, that the bluish-tinged blood of the right half is transformed into the bright red fluid of the left half, evidently owing to the purifying action of the air in the lungs.

Now Harvey was able to complete the picture of the circulatory system of the human body. The big artery arising from the left half of the heart by repeated division supplies the various tissues with blood; from where it is collected by small veins, which join together to form bigger ones, and empty their contents into the right half of the heart. Then the blood begins its excursion into the lungs, from where it is brought back to the left half of the heart, once more to be discharged into the arteries on his endless circuit. The whole work stands out as a monumental example of the triumph of the scientific method in harmonizing discordant facts. It was only careful observation and co-ordination of simple facts; that enabled Harvey to weave such a magnificent tissue of knowledge. The facts of his observation were like beads lying scattered on

the floor, and the circulatory system was the lovely necklace, made by a girl by stringing together the stray beads.

The Swedish naturalist, Linnaeus, showed even from his childhood an absorbing interest in the collection and study of botanical and zoological specimens. In those days, the various forms of life were not properly classified and named. Plants and animals were named according to the whims and fancies of individual workers, without any reference to their relationship to each other. This created no small amount of confusion. The same plant was often known by different names, and the same name was sometimes given to different plants. Linnaeus felt a desire to bring order and harmony into this chaos.

Linnaeus set to work systematically. He examined various kinds of animals and plants and compared their salient characteristics. He grouped together animals having similar structures, and separated those with dissimilar ones. The lion, the tiger, the leopard and the domestic cat, were all grouped together, on account of their resemblances, and received the general name Felis. Each variety of animal was to be given a specific name in addition. Thus the tiger came to be known by the grand name Felis Tigris. He also laid down the essential characteristics of each species, so that slight differences in appearance from individual to individual might not create confusion. For example, the big Persian cat and his small

Indian cousin were all to be known by the name Felis Domesticus. This was the method of naming plants and animals introduced by Linnaeus and adopted all the world over. His simple method brought the multitudinous forms of life to system and order.

Fossils had long been known as the relics of ancient forms of life While the sedimentary rocks of to-day were being formed millions of years ago, by the slow deposition of fine clay layer upon layer, the skeletal remains of the animals of those times got embedded between the several layers. The pressure of subsequent deposits of clay, acting from above for millions of years, hardened the deposits into rocks. In the course of breaking up such rocks, several fossilized remains of ancient living beings were unearthed. Many of these were strange creatures now found nowhere. These fossils were objects of curiosity to the layman and controversy in scientific circles. But nobody noticed any relationship among the various kinds of animals embedded in those rocks, till W. Smith, an English surveyor, began to study them.

In the course of his surveying work, Smith had to examine the structure of rocks in different localities. By careful observation and comparison of the stray specimens of fossilized animals buried in rocks, Smith discovered a regularity in their distribution He found that the various forms of life were not distributed haphazardly. Each stratum of rock had its characteristic type of fossil population;

and the various types were distributed in the same order in different rocks. Since the rocks were formed by the slow deposition of clay through the ages, the type of fossils seen in each stratum should represent into living forms of the age at which it was formed. Thus those relics of ancient life embedded in rocks revealed the progression of organic life on the earth, beginning with simple forms found in the lowest layers, and gradually giving rise to more and more complex ones. What was once thought to be scattered in rocks at random turned out to be in Smith's hands the most orderly handiwork of Nature. He saw in it the history of life on this planet, written on tablets of stone.

The great Greek philosopher, Plato, after long meditation on the harmony of celestial bodies, hit upon the idea that planets move in circular orbits with uniform velocity. For about two millenniums nobody dared question the authority of so wise a man. But the actual paths, obtained by tracing the positions of planets in the sky from day to day, were found to differ considerably from a circle. These discrepancies, however, were explained one way or other, without, throwing the shadow of a doubt on Plato's infallibility. It was Kepler who first felt the unsoundness of Plato's proposition. His acquaintance with Greek ideas of symmetry and harmony led Kepler to believe that the motions of planets should be guided by simple laws capable of being mathematically expressed. To find out these laws was Kepler's great ambition. For this

purpose he joined Tycho Brahe who was the foremost astronomer of his time. Brahe had by assiduous labour and patient observation studied the positions of several stars and planets at different times of the year, with an accuracy marvellous even to twentieth century astronomers.

Kepler made a minute study of the positions of planets as observed and recorded by his master, and traced their courses in the heavens. He proceeded to find out whether the positions of planets from day to day could be explained on the assumption that they were tracing regular geometrical figures. He tried whether ovals, circles, epicycles or different combinations of these, would fit in with the observed positions. But none did. At last he hit upon the idea of an ellipse, and found that it was just the figure described by planets with the sun in one focus. He also found that the positions of planets from day to day, as observed by Brahe, definitely showed that they were not moving with uniform velocity as stated by Plato. By subjecting the available data to a mathematical treatment, he showed that a planet moves fastest when nearest the sun, the velocity getting less and less as it moves away from that globe, and reaching a minimum when it is furthest from it.

Having exploded the Platonic myth, Kepler felt that there should be still greater harmony in the motions of heavenly bodies. He noticed that the time taken by any planet to go round the sun was greater, the more distant it was from the sun.

He racked his brains to discover the exact relationship between the period of revoloution and the distance of a planet from the sun. Formula after formula was tried and discarded when found wanting. We can imagine his face gleaming with delight when a favourite idea seemed to agree with facts, but suddenly assuming a pathetic gloom when more facts disproved it. After many years of trial, Kepler brought to the light of day the mathematical relation which had evaded him for so long. After the discovery of this law, we find him writing with exuberant delight: "What I prophesied two and twenty years ago, that for which I joined Tycho Brahe, for which I settled in Prague, for which I have devoted the best part of my life to astronomical contemplations, at length I have brought to light, and recongnized its truth beyond my most sanguine expectations." To what heights of happiness is a scientist transported when discovery rewards his labours !

The positions of planets as observed by his master, Tycho Brahe, from day to day, were a jumble of apparently disconnected facts, out of which nobody could make head or tail. The steady and persevering attempts of Kepler to systematize them into a general scheme resulted in the discovery of his famous three laws. He revealed the order and harmony that lay hidden in the maze of Tycho Brahe's observations. The mythical "music of the spheres" became a reality to Kepler.

There is a very interesting toy consisting of

wooden cubes, with bits of paper containing portions of a complete picture pasted on them. When the correct faces of the cubes are placed side by side you get the full picture. The individual bits of paper appear to have no relationship to one another. A child, however, with his searching eyes recognizes each bit as part of a whole, for example, as the nose or the hoof of a horse. He establishes a connecting link between the discordant bits, and produces a harmonious whole out of them. Kepler, in reducing the heavenly motions to order, or Harvey, in tracing the course of blood in the human body, did nothing more. The child playing with his toy and the scientist discovering laws are both bringing out the unity in diversity ; and discovery of unity in diversity is the essence of science.

CHAPTER VIII

WEAVING THEORIES TO EXPLAIN FACTS.

It is an estabished scientific fact that matter is made up of atoms and molecules. According to this view, a drop of water consists of trillions of molecules moving about in all directions and colliding with one another. Each water molecule in its turn is made up of two atoms of hydrogen and one atom of oxygen. Atoms and molecules are so small, that they are invisible even under the strongest microscope capable of magnifying objects thousands of times their actual size. Then how does the scientist know that such particles do really exist,—the scientist who believes only in things which he can verify with his senses?

In point of fact, sometimes scientists find it advantageous to believe in the existence of things, which, though not verifiable by actual observation, appears highly reasonable. The simplicity of the laws of chemical combination led Dalton to assume that chemical changes take place between minute particles which he called atoms. The conception of atoms enabled him to explain a number of chemical phenomena. Similarly physicists found out that the properties of gases could be best explained on the supposition that gases are made up of minute particles moving about freely, which they called molecules. Moreover, the idea of molecules enabled them to understand what heat

really is. Since gases are converted into liquids and soilds on cooling, the latter also should be made up of molecules. Further discoveries indicated that the molecules are not the same as Dalton's atoms, but are made up of them. With all the evidence at their disposal scientists could now conjure up a living picture of atoms and molecules. Not only did later discoveries in science not contradict the conception of atoms and molecules, but every new discovery supported it, till at last it has become one of the living articles of faith to the scientist.

When known facts are found insufficient to explain a phenomenon or a group of phenomena, the scientist imagines the existence of things, in the light of which the observed phenomena become clear. He calls the new conception a theory. It provides a golden thread to link together facts of observation. A law too links together facts of observation; but it does not go beyond them; it is only a generalization of observed facts. A theory, on the other hand, inrolves some imaginary conception not contained in the facts of observation. The scientist does not, however, give free play to his fancies like a poet. He sobers the fiery steed of imagination with the reins of cold reason. Though his sweeping imagination brings home images and ideas, they are discarded when found inconsistent with observed facts. So long as the idea co-ordinates facts without contradicting any one of them, it is maintained as a theory. When it

is verified by observation, or shown to be highly probable by overwhelming evidence, it is raised to the status of a law.

Kepler had reduced planetary motion to order and system, but could not give an explanation for the simplicity he revealed. Sir Isaac Newton, however, decided to trace the cause of this beautiful harmony. Kepler had shown how the planets moved; now Newton would explain why they moved so. As an adequate explanation in terms of known facts was not forthcoming, Newton realized that he should seek the explanation in facts not yet known. Kepler had merely connected together known facts into laws. Newton would have to imagine the existence of new facts. By studying the forces acting on moving bodies on the earth, he realized that the secret of the simplicity of planetary movements lay in the existence of similar forces among heavenly bodies.

To find out the nature and manner of action of those forces was his great ambition. Newton knew that all the great men, who had attempted to solve the problem before him, had made a great mistake. They thought that some external force was necessary to drive the planets round in their stately procession. But Galileo had already shown that no force is required to maintain a body in motion in a straight line. Once it is set in motion it moves on for ever. So no force is required merely to keep the planets going. But some force is necessary to deflect them from straight paths, and make them

describe ellipses round the sun.

Newton showed, by a mathematical interpretation of Kepler's laws, that the force keeping the planets in their elliptical orbits should originate from the sun. But if there is such an attractive force constantly acting on the planets, why are they not ultimately drawn into the sun? To save the planets from such a catastrophe, there should be some other force also at work. When we tie a stone to the end of a thread and holding its free end whirl it round and round, we feel it exerting a pull on our hand. In fact, a body revolving round a point tends to get away from it. Planets too, since they go round and round the sun, should be repulsed from the centre. So it should be this repulsive force that balances the attractive force of the sun. By equating these two forces, Newton was able to derive the mathemattcal formula expressing the intensity of the attractive force between any planet and the sun.

But does such a force exist? Or is he building his formula on an airy foundation? An apple falls to the ground when ripe. A stone thrown up returns to the earth. So there should be a force pulling down apples and stones to the earth. Is this what is called gravity? If so why should not the influence of the force extend to the moon? If it does, the motion of the moon round the earth is explained. Again, why should gravity be confined to the earth and the moon? Why should not the sun too exert a similar force on the planets?

This should be the force that his equation indicated. This should be the secret of the solar system and of the Universe.

Newton's imagination was set aglow. He saw the appales being pulled down by invisible cords emanating from the centre of the earth. He saw the same cords radiating from the sun, and reaching out to the outermost planets keeping them in their regular orbits. He could not actually go to the sun and verify the existence of the force. He satisfied himself, however, that the assumption of such a force not only agreed with all known facts, but also afforded a reasonable explanation of the motions of every heavenly body revolving round another. It was to the motion of the moon round the earth that he first applied his theory. He was very much gratified to note that the actual path of the moon agreed remarkably well with that calculated on the basis of his theory. He also showed that all the regularities of planetary motion could be explained by a simple application of his theory. Thus the imaginary idea, which stole slowly and gently into his mind, when put in mathematical form; and when supported by observational evidence, appeared to be a great secret of the Universe. That was how the famous Theory of Universal Gravitation took shape in Newton's mind. According to this theory, any two material bodies are attracted towards each other with a force depending on the distance between them and their masses.

Now let us see how Charles Darwin developed

his famous Theory of Natural Selection to explain the phenomenon of organic evolution. While he was a five-year voyage round the world as the naturalist to a surveying expedition, Drawin got many opportunities to come in contact with myriads of living and fossil animals. He compared the appearance and anatomy of animals found in different continents, and noticed their gradual variation from place to place. The animals inhabiting an island, though differing distinctly from those on the mainland, showed many resemblances to them. He also found a similarity in type between living animals and certain extinct forms preserved in fossils. These facts, according to Darwin, afforded striking evidence to prove the reality of organic evolution, which was a much-discussed problem of the day.

All his observations indicated unmistakably that, ever since the beginning of the world, there had been a gradual emergence of complex types of living beings from simpler ones. The gradual variation in the same species of animals from place to place, from mainland to the island, and from wild life to domesticated life, indicated that environment was responsible for the emergence of new species. But Darwin could not suggest how exactly changes in environment could elaborate such multitudinous forms of life as inhabit this earth. In other words, he was not able to visualize the details of the process, by which the same kind of animals gave rise to different species.

It was while the great naturalist was deeply engrossed in this problem, revolving in his mind all the possible methods of Nature in the creation of new species, that he happened to read a book on population by Malthus. The book dealt with the natural forces that work in checking the human population of a country. War, famine, epidemics and other pestilences sweep down occasionally like a hurricane and take a huge toll of human lives. Obviously the individuals that succumb to these calamities would be the unhealthy and those least fitted to withstand the ordeal. Suddenly it flashed through Darwin's mind that such natural agencies of destruction should be more ruthless among animals. Animals multiply more profusely than man for one thing, and for another they are less able to counteract the forces of destruction. Darwin knew that even members of the same species vary from individual to individual in their colour and the shape and size of their organs Some of these variations would be advantageous to the animals in times of distress and famine, or when the environment changes.

Take, for example, birds, which like our domestic fowls are poor fliers. Quest for food brings them to the marshy regions near the banks of a river. Soon they discover the swimming wealth of the waters and make free inroads into it. The frightened fish, however, find it easy to escape from the narrow and pointed beaks of the fowls Pointed beaks served them well on land for

pecking. But to catch fish broad beaks are more useful. When food becomes scarce in the land the birds have to rely more and more on the watery pastures, as they cannot fly away to more hospitable countries. Those with slightly broader beaks than the average find it easier to catch fish. In course of time, the birds with the narrowest beaks get exterminated by hunger. Among the survivors those with the broadest beaks thrive best. The process of elimination works steadily and ruthlessly, till after tens of thousands of years a broad flat beak becomes the regular feature of the bird.

In the meantime, other anatomical changes also take place. The birds would have early realized that, to be more efficient as aquatic hunters, swimming is an indispensable art. When the nimble fish outstrip their enemies, and flee away to deep waters, the more courageous birds goaded on by hunger, follow the prey to dangerous depths. Thus they stumble into the art of paddling out of sheer necessity. But only those with a little tissue of skin between their toes and have light bodies would be successful, so that these variations from the average also would stand at a premium. Through generations, they become broad-beaked, web-footed and light-bodied, till after thousands of years a duck-like bird evolved.

Now the whole problem became clear to Darwin. Malthus had furnished the spark, and Darwin's brain flared up in scientific imagination In his mental eyes the earth seemed a vast arena,

where the multitudinous forms of living beings tried to get a foothold. He saw the entire creation travailing and struggling for existence. Individuals with advantageous variations from the average members of the species were found to be better fitted to adapt themselves to their surroundings, and react to new situations. He saw the unfit collapsing under the strain. The fit alone survived and propagated. In the course of ages, what was once a variation in certain individusls became the normal characteristic of all. In other words, a new species had been evolved. This is, in brief, the famous Theory of Natural Selection proposed by Charles Darwin as an explanation for organic evolution.

Darwin, however, did not immediately proclaim his ideas. Like a true scientist, he wanted to test whether those ideas were in agreement with facts. Not satisfied with the wealth of information he gathered during his voyage, he continued his study with unabated diligence even at home. He collected thousands of living forms from different localities, and studied their anatomy. The fossil remains embedded successively in the different layers of sedimentary rocks also received his careful attention. He experimented with animals in his extensive garden to observe their reactions to changes of conditions. He also noted the gradual changes undergone by wild animals in domestication. He collected and generalized facts. His eyes were impartially open to very fact and

phenomenon that presented itself before him. After several years of experiments and study, when it became clear to him that all the facts of his observation agreed with his theory, he published his views in his great book, "The Origin of Species."

A theory is a scheme of explaining a group of facts, conceived by imagination and guided by reason. It is valuable to the scientist only in so far as it agrees with known facts. Whenit goes against any established law of nature, it is immediately thrown overboard. Newton's Theory of Universal Gravitation was tested in numberless instances; and never was it found necessary to doubt its validity.* So it is raised to the status of a law; and everybody refers to it as the Law of Universal Gravitation. That is how an imaginary idea gets established as a scientific truth by the accumulated evidence of years.

Darwin's Theory of Natural Selection, on the other hand, has had a tempestuous career. Ever since it was first postulated, it has been the subject of constant attack by biologists. It has already been modified, and one does not know how much

* Accurate observations of the course of the planet Mercury round the Sun seemed to differ from that calculated on the basis of the Law of Gravitation. It was later on shown, however, that this was owing to a mistake in the value taken for the mass of the planet which, according to modern theory developed by Einstein and others, should change with the velocity of the planet. In other words, a new factor has been brought to light necessitating the modification of old ideas but without invalidating them. Einstein does not supplant Newton but supplements him.

of Darwin's original idea will survive modern research in heredity.* And yet the theory of Natural Selection has done a signal service to biology. It opened up a new field for investigaion, and illuminated the path of the research worker. It is decidedly advantageous to work in the light of some theory or other, even if it has to be ultimately modified beyond recognition or even discarded as an untruth. Theories play an important role in the progress of science; and the imaginative reasoning capable of weaving theories is an asset to a discoverer.



* De Vries showed that mutation plays a more important role in evolution than natural selection.

CHAPTER IX

KNOWN FACTS SUGGEST NEW ONES.

It may come as a surprise to many, but is all the same true, that the intellectual process behind may scientific discoveries was some simple act of reasoning. Strikingly novel ideas have often suggested themselves directly from known facts. While the scientist reflects on a well-established scientific principle, a new idea related to it may occur to his mind. Or he may wonder why a principle useful in one field of science should not be applied to another. He proceeds straightway to perform suitable experiments, to put the suggestion to the test. Many scientific discoveries have been the results of such investigations.

Imagine a child standing near a kitchen fire. He feels the heat of the fire at some distance from it. He remembers how intensely hot one feels, when one remains in the open air exposed to the sun. It requires on previous notion regarding the nature of the sun for the child to infer that the sun should be a globe of fire. Otherwise, how can it produce so much heat from such a great distance? The child explains the heating effect of the sun in terms of the familiar kitchen fire. This is precisely what the scientist does so often. While studying a simple phenomenon, its similarity to a strange and complex one may suggest itself to the scientist, and enable him to explain the unknown phenome

non in terms of the principles known to be true of the simple one.

It has been known for a long time that a magnetic needle suspended at its middle point always sets itself in the north-south direction, provided it is outside the influence of other magnets That end of the needle which points to the north is called the north pole, and the other end the south pole. For a long time after the discovery of the phenomenon, nobody could adequately explain why the north pole of the needle should always point to the north. The ancient thinkers had attributed it to the attraction of some big mountain in the north full of magnetic stones, or some star in the northern sky.

Dr. Gilbert, an English physicist and a keen student of the properties of magnets, was engaged in the study of the behaviour of a magnetic needle towards magnets of different shapes. One of the magnets he had in his laboratory was a large spherical one. While holding a magnetic needle over different positions on the sphere, he noted that, wherever on its surface he placed the needle, its north pole always pointed to the same end of the sphere, and the south pole to the opposite end. As he knew that opposite poles attracted each other, he could easily explain the behaviour of the needle towards the sphere. Evidently the south pole of the spherical magnet was attracting the north pole of the needle. The readiness with which the north pole of the needle always pointed to the

south pole of the spherical magnet looked very much like the constant deflection of the north pole of a needle towards the north, when it is placed outside the influence of any other magnet. At once it occurred to Dr. Gilbert that the earth itself might be a big spherical magnet, with its south pole at the geographic north pole and its north pole at the geographic south pole. On that assumption, it could be easilly explained why the north pole of a magnetic needle is always deflected to the north. Thus a simple analogy solved a problem, which had puzzled scholars for a long time.

Benjamin Franklin, the great American statesman, used to occupy his leisure in doing electrical experiments. He bought an electrical machine which was one of the novelties of the day, and took delight in entertaining himself and his friends by producing electric sparks from the machine. It was a beautiful sight to observe the sparks flashing from one wire to the other in zig-zag paths. But if you had watched the famous statesman witnessing the spectacular phenomenon, you would have at once realized that he was not so much enjoying the beauty of the sparks as being absorbed in some deep problem.

The accepted explanation of the phenomenon was that the spark was caused by the skipping of electricity from one wire to the other, the intervening air being heated in the process. The spakrs suggested to Franklin's mind the phenomenon

of lightning. The apparent similarity between the two phenomena kept revolving in his mind; and it was not long before he felt conviced that one was an imitation on a small scale of the other. The colour of the light emitted, the crackling sound, the instantaneous motion of the spark, its shattering and burning properties, all pointed to lightning as a mere flash of electricity from clouds.

Before his time people entertained all sorts of fantastic ideas about the origin of lightning. Some said it was due to the explosion of gases in the atmosphere; and others attributed it to the sudden rushing forth of wind from inside the clouds. Benjamin Franklin, however, perceived the obvious absurdity of these views. He proceeded to establish the truth of his surmise, by showing that clouds actually accumulated enormous charges of electricity.

Franklin proposed to post a metallic rod on the summit of a high steeple, with a view to draw electricity from the clouds. While trying to raise the necessary money for his project, the happy idea flashed through his mind that, instead of erecting a steeple, he could as well use a kite. Accordingly he flew a kite high up among the clouds, expecting electricity to stream down the twine carrying the kite. He tried to get sparks from the metallic key which he had tied to the twine carrying the kite, but failed. While he was doubting the validity of his guess it began to rain. Then on trying again he got a good spark. He

repeated the experiment and succeeded again and again. The rain had wetted the twine, and only then it became a conductor of electricity. Franklin demonstrated also that electricity drawn from the clouds had the same properties as electricity obtained from electrical machines. Thus he established the fact that lightning is nothing but a discharge of electricity from the clouds. Here again, it was a simple analogy that led him to the discovery.

Water-wheels continue to be a regular feature of our country-side, though the steam-engine is slowly ousting this ancient means of forcing out water from paddy-fields. A water-wheel consists of a number of broad spokes radiating from the axle, and is placed in a narrow channel just wide enough for the spokes to pass through. A man sits by and turns the wheel round and round with his feet. Each spoke pushes forward the water in front of it, and a regular current is thus set up along the channel.

Imagine a boy watching the water-wheel going round and round, and forcing the water up the channel. He sees a wheel rotated by man producing a flow of water and he wonders whether the reverse process will work; that is to say, whether running water can set a wheel in rotation. If it can, the rotating wheel may be made to do some useful work, for example, to run the machinery of a rice-mill. If the boy is inquisitive enough to put the idea to the test by placing the wheel in a

rapid stream, he will find to his delight that the wheel turns. The boy has discovered a means of harnessing the energy of running water; and it was a simple act of reasoning that showed him the way.

The discovery of the deflection of a magnetic needle, when brought near a metallic wire carrying an electric current, captured the interest of the whole scientific world. It filled particularly the mind of Michael Faraday, while he was working in the Royal Institution. He studied everything known up to then regarding magnetism and electricity. Gradually the conviction grew stronger and stronger within him that there should be an intimate connection between the two. A freely suspended magnetic needle would ordinarily set itself in the north-south direction. The discovery mentioned above was that, when such a magnetic needle was brought near a metalic wire carrying a current of electricity, the needle was deflected from its north-south direction. Hence a current of electricity in a metallic wire should produce in its neighbourhood some change which causes the deflection of a magnetic needle. If so, would a magnet produce some change in its neighbourhood, such as would induce a flow of electricity in a metallic wire? Faraday thought it should if magnetism and electricity were interconnected.

He proposed to place a metallic wire under the influence of a strong magnet. To bring as long a wire as possible within the action of the magnet

the wire was wound in the form of a coil, and a magnet was introduced into the coil without touching it To see whether any electric current was flowing in the wire, he connected it to an instrument capable of detecting even small currents. He was greatly disappointed not to get the slightest trace of a current. He returned to the experiment again and again at intervals, but without success.

At last, Faraday noticed that, every time he introduced the magnet into or took it out of the coil, a momentary current flowed through the wire. This current was so feeble that it had escaped his attention all the time. Faraday soon realized that it was not the presence of the magnet, but its motion with reference to the coil, that produced the current.

This suggested to Faraday that, instead of moving the magnet in and out, the wire could be moved in the neighbourhood of the magnet. He took a strong magnet in the form of a horse-shoe, and waved a copper wire between its ends. He was delighted to notice that the operation was accompanied by a flow of electricity through the wire. It did not matter whether the wire moved or the magnet moved. Whenever the one moved relatively to the other, a current was produced in the wire. It was thus that Faraday discovered the principle of the dynamo. To-day in big industrial towns, in forlorn hilly tracts and in the depths of wild forests, engineers generate electricity by rotating coils of copper wire between the ends of

magnets. Faraday was told that a metallic wire carrying a current of electricity produced movements in a magnet suspended in its neighbourhood; and he showed the world that a current of electricity could be produced in a metallic wire by moving it relatively to a magnet.

While he was engaged in his researches on automatic telegraphy, Edison found it necessary to pass a needle over a cylinder, carrying a paper on which the Morse characters were imprinted by a series of indentations. When the cylinder was rotated rapidly, the tracing needle ran merrily over the paper giving off a humming sound. The sound had a musical rhythm about it which gave it a resemblance to human speech. Edison knew that the indentations caused the needle to vibrate with great rapidity. The vibrations of the needle produced certain pulsating waves in the air, similar to the ripples produced by a stone dropped into a still pond. These waves on striking human ears produced the sensation of sound. The resemblance of the sound thus produced to human speech suggested to Edison that it might be possible to produce the various sounds made use of in speech by mechanical means. If indentations could give rise to vibrations of material objects, and the vibrations to sound waves in the air, why may not sound waves be made to produce vibvations of material objects, and the vibrations in their turn indentations on some impreseible material? And these indentations when run over by a needle

should hum out the original sound just as the Morse characters did

It was not long before Edison set out to put these ideas to the test He made a thin membrane vibrate in concert with the sound waves caused by human speech. The vibrations of the membrane were transmitted to some soft wax on a rotating cylinder, on which they produced corresponding indentations. On keeping, the soft material on the cylinder was hardened. When the cylinder was now rapidly rotated under a tracing point, the indentations gave off sounds which closely resembled the original speech. This was the machine which, when modified and improved, and the cylinders replaced by plates, appeared in the market as that wonderful little musical box known as the gramophone, singing its melodious songs in obscure hamlets and busy cities. If indentations produce sound waves, why may not sound waves produce indentations and the indentations reproduce the sound waves ?

Now let us return to the boy who discovered the use of a water wheel in harnessing the energy of running water. Imagine that, after strolling for a time in the paddy-fields, he climbs up a neighbouring hill. The force of the wind at the top of the hill sets him thinking whether the energy of the wind can be utilized for doing mechanical work. If running water can set a wheel rotating why may not air in motion do the same ? If the boy make a light wheel with broad vanes and places it i

wind, he will after overcoming a few practical difficulties, find the wheel going round and round; and, if the rotating wheel is connected to suitable machinery, it may be made to do useful work. The boy has discovered the principle of the windmill; and he has done this by testing whether what he learned about running water was true of wind also.

Many scientific discoveries have been the results of attempts to extend a principle known to be applicable in a few instances to others also. The discovery of the metal pottassium illustrates this point. Let us get into the Royal Institution in London, and watch Sir Humphry Davy attempting o isolate the metal known to be present in caustic potash. Chemists knew that it contained a metal, because similar substances yielded metals on analysis. Several chemists had tried in vain to obtain the metal before him. It occurred to Davy that, a few years before, physicists had discovered that, when a current of electricity was passed through water, it was decomposed into its elements. If electricity could decompose water, why could it not decompose caustic potash too? Davy would at once put his idea to the test.

We see him taking a stick of caustic potash in a metallic plate, and touching the pstash with the two wires from his battery. The heat generated by the electric current melts the potash, and Davy notices the formation of small globules of a lustrous metal bursting out of the molten potash. His joy knows no bounds- He gets so excited that he

dances about the room in sheer ecstacy. He has for the first time brought to light the metal potassium, which so many before him had yearned to see. It is a fascinating sight, tndeed, to wetch a scientist rejoicing in a great discovery-

The work of Louis Pasteur in the field of hygiene is a beautiful example of the successive application of known principles to new problems. During the nineteenth centurp, the brewers of France were faced with a very depressing situaton. Sometimes the rich delicious wire made in their factories turned sour and became unfit for drinking. All their attempts to cure this malady ended in failure. Louis Pasteur, himzelf a chemist, realized that it was the duty of the chemist to inquire into the cause of this disease. Chemists had till then confined their attention to chemical changes undergone by mineral substances. They considered the chemical changes in animals or vegetable produdts as a field apart, and left them severely alone. But Pasteur could not understand why ihe principles ol chemistry, which yielded such revealinq results in the domain of mineral substances, should not be extended to animal and plant products.

He proceeded to investigate the chemical changes taking place in the souring wine, and to search for the agents brtnging about such changes. He made a careful study of the nature of both healthy and sour wine. On examining them under he microscope, he found minufe solid particles

floating in them. In one, the particles were spherical, and in the other elongated. On closer examination, they were found to be minute living organisms capable of multiplying rapidly. One kind when placed in a sugar solution changed it into alcohol. When the other kind was added, the alcohol was converted into an acid : and acids were known to be sour in taste. The souring of wine should, therefore, be due to the conversion of the alcohol in the wine to an acid. And so it should be the second organism that caused all the havoc to the brewer. The organism like tiny chemists were bringing about chemical changes of the same kind as those taking place in the laboratory.

It remained to show how these micro-organisms found their way into the wine. By a series of delicate experiments, Pasteur demonstrated that the organisms concerned were always present in the air, and so could gain access into the liquor. Further, when all the microbes in the wine as well as in the air were destroyed by heating, the wine did not get sour at all. Thus Pasteur provided the brewers with a means of preventing a blight, which had become the curse of their profession.

All the great chemists of his day were against Pasteur when he embarked upon the new field. Even his well-wishers advised him to put an end to such fool-hardy investigations. Pasteur, however, felt convinced that the complex changes undergone by plant and animal products could be

studied on the well-established principles of ordinary chemistry. Chemical changes taking place in the test-tube showed him the way to the mysterious processes in the fermenting liquids.

On extending his investigations into other changes taking place in plant and animal products, Pasteur discovered that each of those changes was caused by a specific organism. He found, for example, that the souring of milk was due to certain microbes, which he was able to isolate. It was not a far cry from chemical changes undergone by fluids such as wine and milk, which are the products of living processes, to the chemical changes taking place within living tissues. He took, for example, the vexed problem of the ulcer caused by a wound in the human body. The surgeons of his day had a vague idea that the cause of the ulcer was some organiam generated in the flesh itself. Pasteur, however, recognized the close similarity between the fermentation of a grape-fruit and the putrefaction of a wound. He suggested that the microbes causing the ulcer should come from outside. An opened grape did not undergo fermentation, if scrupulously kept away from the reach of the microbes concerned. So too, Pasteur showed that a wound would not develop into an ulcer, if kept free from the microbes causing the decay of the flesh.

It was this principle that became in Lord Lister's hands the instrument of relieving the miseries of millions of suffering men and women.

Lister's discovery was that the best means of destroying those germs without injuring the flesh was by using a solution of carbolic acid. He showed that surgical operations could be performed without any danger of the wound developing into an ulcer, if the dressings and the instruments were treated with carbolic acid.

Pasteur advanced further and said that, just as the disease of the wine and the putrefaction of wounds were caused by definite microbes, many animal ailments also might be due to specific microbes, which bring about certain chemical changes in the body injurious to its well-being. Pasteur was able to prove his view, in the course of his investigattons into some of the diseases raging among the farm animals at that time. He was able to isolate the germ of every disease he studied. He allowed the germ to grow in a fluid containing the food materials necessary for its growth. It multiplied into millions in a day or two ; and when, the culture containing the germs was injected into healthy animals, they took the disease, proving unmistakably that the cause of the malady was the germ.

At this stage Pasteur's work received an impetus by a momentous though accidental discovery. While working with the germs of chicken-chlera, Pasteur found that when a culture of the germs which had been left unnoticed in a corner for a long time was injected into fowls, they took only a very mild form of the disease. What

was more surprising to him was that those fowls became immune from any further attacks of the disease. This was a wonderful discovery indeed. By merely cultivating the germs of a disease for a long time, he got a culture which could even prevent the incidence of the disease.

Pasteur began to apply the remarkable discovery to the various contagious diseases prevalent in France at that time. At first he had a host of opponents who refused to believe in his discoveries. They did not like the idea of a chemist intruding into the province of the physician. But Pasteur saw no reason why the principle which he had shown to hold good for fermenting grapes, souring milk and putrefying ulcers should not be applied to contagious diseases too. When, at last, he gave a public demonstration of the efficiency of his method for preventing anthrax in domestic sheep, his enemies were all silenced.

Anthrax was the despair of the shepherds of France at that time. Countless sheep were wiped away by the pestilence. Pasteur wanted to try whether his method of preventing chicken-cholera could be applied to anthrax. He took twenty-five healthy sheep, and vaccinated them with the weak serum got by keeping a culture of anthrax germs for a long time. After a few days he injected a fresh culture of anthrax into the twenty-five vaccinated sheep and twenty-five unvaccinated ones. When the sheep were inspected after a few days, the vaccinated sheep were all healthy.

whereas the others were dead or dying. This was a spectacular triumph for Pasteur.

The crowning glory of Pasteur's researches was his discovery of the treatment for rabies, an achievement which has earned for him the eternal gratitude of humanity. The symptoms of the disease suggested that it should be the brain of the animal that was affected by the disease and served as the seat of the poison. So he prepared an emulsion of the brain of a mad dog, by grinding it to a powder in the presence of a suitable liquid. When inoculated into healthy dogs, the emulsion invariably gave rise to rabies. Pasteur searched in vain for the specific microbe in the emulsion. The microbes might be too small to be seen even under the microscope. But that did not mean that his methods with the microbe-culture should fail here. Guided by this view, he proceeded to weaken the rabies serum, by keeping the brain for some days before preparing the emulsion from it. In delightful agreement with his expectations, he found the resulting fluid capable of giving dogs immunity from the disease.

Pasteur had still a problem to solve. By injecting the serum he could render dogs immune from rabies. But what about one already bitten by a rabid dog? Pasteur had a vague belief that his serum would be efficient in such cases also. When he actually put the idea to the test, he found to his immense satisfaction that dogs even after being bitten by a rabid dog, could be made

immune from rabies.

Now it remained to apply the knowledge gained from dogs to human beings. Pasteur yearned but dreaded to take that bold step. Fortunately an opportunity offered itself soon. A boy was brought to his laboratory two days after he was bitten by a mad dog. Pasteur, after consulting many physicians and assuring himself that there was no other means of saving the boy, decided to use him as the subject of his experiment. The anti-rabic inoculation was administered to the boy for ten days. Pasteur watched the patient from day to day with mingled feelings of hope and fear. The experiment was an unqualified success. This first triumph encouraged Pasteur to try other cases too, all of which were successful. An infallible remedy had been discovered for a fell disease, which had as yet baffled the physicians of all climes. Since then, millions have reaped the fruits of the discovery, blessing the name at their benefactor. In India we have honoured him by naming the institute in Coonoor where anti-rabic serum is manufactured the Pasteur Institute.

Pasteur's achievements were but the beginnings of a series of brilliant conquests of disease. Microbes causing many contagious diseases were isolated. Deadly scourges like malaria, yellow fever, sleeping sickness, plague, typhus fever etc., have yielded to the power of science. Pasteur's work stands out as a beautiful edifice of scientific knowledge built up step by step, by the application

of the principles of chemistry to more and more complicated problems. From the chemistry of sulphuric acid and potash to the chemistry of fermenting liquids, from the microbes of the diseases of wine to the microbes of animal ailments, and finally to the microbeless virus of rabirs, was a wonderful march of scientific knowledge.

The mysteries of Nature unfold themselves layer after layer. The scientist pushes forward well-known principles to ever-new fields of research. Old ideas suggest new ones, which are immediately put to the test. If they emerge successfully from the test-house of experimental verification, they are absorbed into the body of scientific knowledge, and suggest in their turn new ideas to thoughtful minds. Science blossoms forth like this in ever-widening whorls.

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CHAPTER X

PREDICTION OF NEW FACTS.

Facts, established by experiment, and absorbed into the body of scientific knowledge, not only suggest new ideas, but very often enable the scientist to foretell the existence of unknown facts with absolute certainty. Imagine a boy who is told that Mars is a planet just like our own, having an atmospheric envelope, and rotating on its own axis. The similarity between Mars and the Earth would suggest to the boy's mind that there may be living beings in Mars. It is only a possibility based on analogy, and for all that we know may turn out to be an untruth.

If, on the other hand, the boy infers from the rotatory motion of Mars that there should be night and day on that planet, he has discovered an astronomical truth of no small importance. The boy is able to say what is happening in a distant planet without actual observation. If the data on which the prediction is based are correct, and the reasoning is faultless, the final conclusion should be positively true. It is not a guess or a possibility but an indisputable certainty: though to be accepted as a scientific fact it is should be verified by actual observation.

It is in the same way that astronomers are able to predict the times of solar and lunar eclipses with marvellous accuracy. The method was the

same, though involving complicated mathematical calculations, by which Halley predicted that the comet which had visited the earth in 1682 should reappear in 1758. Not only did it blaze the sky in 1758, but also in 1835 and 1910, as foretold by Halley. The occurence of a solar eclipse or the appearance of a comet at the predicted time no longer arouses any thrill, since they have become so common. But it is not only events that recur at regular intervals that scientists can foretell. They have often predicted entirely new facts from known data. The starting ideas were so sound, and the various steps by means of which the final conclusion was arrived at were so faultless, that the predicted fact appeared to the scientist as real as if it had been actually observed. Such predictions have played a vital part in the history of science. They fostered research and directed it along fruitful channels, till at last the prediction became a practical reality.

The discovery of Neptune is one of the most interesting episodes in the history of astronomy. The momentous discoveries of Kepler and Newton had reduced the motions of planets to system and order. Better telescopes and finer instruments for determining the positions of heavenly bodies were invented. The velocities of all the planets were calculated, and their positions from day to day for many years ahead predicted.

By actual observation through the telescope, the positions of the planets were found to be juts

those predicted on the basis of the laws of Kepler and Newton, but for a single exception. The planet Uranus seemed to be annoyingly unpunctual. It would be either a little behind or a little ahead of the predicted time. It could not be that the Law of Gravitation, which guided the movements of all celestial bodies, would fight shy of Uranus. It was known that apart from the gravitational pull exerted by the sun on all the planets, they attracted each other when they came near enough. In calculating the positions of Uranus, due consideration was given to the disturbing influence of Saturn, the nearest neighbour of Uranus. Even then, the motion of Uranus seemed to violate the Law of Gravitation.

If the Law of Gravitation was true, the irregular movements of Uranus could be explained only on the assumption that it was being attracted by an unknown planet, tracing its lonely course somewhere out in space. Uranus was till then regarded as the most distant planet from the Sun. Now it appeared that there is another planet further away! If it were nearer it would have been observed long ago. By measuring how far Uranus lagged behind, or went ahead of the calculated positions, the astronomers calculated on the basis of the Law of Gravitation the exact position of the unknown planet and its mass. In fact the new planet seemed so real to the astronomers that they saw with their mental eyes the massive globe out in the darkness, disturbing the stately march of Uranus.

Thus the new planet had already been discovered in the astronomers' minds, not as a guess or probabiliiy but as an unquestionable fact. It was as real to them as Jupiter or Saturn. Yet to be included in the scientific body of astronomical facts, it had to be actually observed. So astronomers were busy scanning the heavens for the new planet At last, a German astronomer, scrutinizing the region of the sky were it was expected to be according to calculations, saw a new star which was not present in the star map of that zone. Looking for it again the next day, he found that it had changed its relative position among the stars. This proved that it was not a star at all but a planet. Its position from day to day was noted and found to agree with the calculated one. Thus the new planet predicted by astronomers' was at last brought to the realm of reality and named Neptune.

According to the Atomic Theory, matter is made up of extremely fine particles called atoms. Each element has tts own kind of atoms different from the atoms of other elements. It was shown by Mendeleeff, a Russian chemist, that the chemical elements, when arranged in the ascending order of the weights of their atoms, show a repetition of properties at regular intervals. Every successive eighth element was found to resemble the first. In other words, the second, the ninth and the sixteenth elements, behaved very much alike; so too did the third, the tenth and the seventeenth, and so on. As a consequence of this regularity,

when the elements were written down in the order of increasing weights of their atoms in horizontal rows of seven, similar elements fell into the same vertical group. For example, the elements which occupied the first place in all the horizontal rows, and therefore forming the members of the first vertical group, resembled one another. All known elements could be accommodated to this scheme with slight modifications. The chemical elements were thus knit together into a harmonious system of families. Mendeleeff called the arrangement the Periodic Table.

There was, however, one difficulty about Mendeleeff's scheme. He found that, when the elements were arranged in the order of the weights of their atoms, the like elements would fall into the same vertical group, only if a few places in the table were left vacant. For example, if the eighteenth element were to be given the eighteenth place, it would not find itself among its brothers. If, on the other hand, it were allotted to the nineteenth place, and the nineteenth element to the twentieth place, and so on, they would all fall snugly into their family groups So Mendeleeff left the eighteenth place a blank and said that the eighteenth element was really the nineteeth.

Then what about the eighteenth element? Mendeleeff said that there was an undiscovered element, the weight of whose atom should be between those of the seventeenth and the nineteenth elements. He went a step further and

predicated the properties of the unknown element from the properties of its known brothers Mendeleeff felt certain that, if the law embodied in the Periodic Table was true, the eighteenth place should be left vacant for a new element lying hidden somewhere with all the properties with which he had invested it. When a few yers later, the eighteenth element was actually discovered, it fulfilled Mendeleeff's predictions remarkably well. Long before chemists saw it with their eyes. Mendeleeff had discovered it in his Periodic Table. Even now, there are two vacant places in the Periodic Table representing two missing elements. When in future, those elusive elements cross the path of some lucky investigator, he will merely have to verify the properties to those elements which were known to every chemist even now.

The discovery of "wireless" waves is another example of an experimental verification of a theoretical prediction. The vital relationship between electricity and magnetism, so lucidly brought out by Faraday's experiments, was expressed in the form of mathematical equations by Maxwell, another English physicist. On simplifying the equations, Maxwell obtained a new equation, which at once struck him as the mathematical expression for any kind of wave motion. By closly examining the various factors involved in the equation, its full physical significance became clear to him. He predicted from his equation that, if electricity was made to surge up and down a metallic wire in

quick succession, the wire should radiate into space a kind of "electric" waves. These waves should resemble the ripples on a smooth sheet of water, or sound waves in air, but with the fundamental difference that the "electric" waves would not require any material medium for their transmission.

The idea was so entirely novel that Maxwell could neither make electricity oscillate in quick succession, nor prove the existence of his "electric" waves. Many scientists regarded his equation as a mere collection of symbols which he had stumbled upon by mathematical jugglery. For Maxwell, however, his equation was the mathematical expression of actual physical facts.

Fifteen years later, Hertz, a German physicists, succeeded in producing oscillaticns of electricity in a wire with astounding frequency. He went about the room with a loop of wire to detect any waves produced as a result of the oscillations. Hertz found that a kind of electric waves were really being produced and radiated from his apparatus, and foretold by Maxwell. On further studying the properties of these waves, Hertz found them to fullfil Maxwell's predictions to a surprising degree. These are the waves which are used at the present day in wireless broadcastng. Maxwell saw the vision of these waves in his equations. So long as the idea remained a collection of mathematical symbols, it could not be accepted as scienfific truth. In the hands of

Hertz, however, the mathematical symbols took a physical form and became part of scientific knowledge.

By a mathematical treatment of his famous Theory of Relativity, Einstein, the great German mathematician, came to the conclusion that light should be attracted by matter, as if light were a stream of material particles. He could actually calculate the angle of deflection of a ray of light shooting past a huge body capable of enormous gravitational attraction. This was a novel idea to the physicists. So far they had scrupulously kept apart matter and a form of energy like light. Newton's law provided for gravitational attraction between material bodies only. That light too is subject to the same force was a hard nut for them to crack. For Einstein, however, the mathematical formula expressing the deflection of light by matter seemed as real as any fact experinced by the sense. The physicists, any way, would believe it, only if they could actually see the phenomenon for themselves.

Owing to the enormous speed of light, a prodigious mass is required to deflect a ray of light from its path to any appreciable extent. So no earthly object would produce any effect at all; and if Einstein's idea is to be tested, the phenomenon should be looked for in celestial bodies. Imagine the light, for example, coming from a distant star seen just outside the circumference of the sun. The distance of the star from us being thousands

of times greater than the distance of the sun, the light of the former will fade away in the brilliant blaze of the latter But during a solar eclipse, the sun is hidden by the moon, and a number of stars become visible from the background. If now the positions of the stars whose light just skims past the sun be noted, and compared with their positions when the sun is not anywhere in the field, any deflection of the light by the sun's attraction could be easily measured.

During the solar eclipse of 1916, astronomers and physictsts flocked to all the convenient spots in the remote regions of South America, and the islands off the cast of West Africa, from where the solar eclipse could be best observed. At the predicted time they were all ready with their instruments to observe and photograph the sun. They peered through their telescopes watching the grand sight of the solar globe being swallowed by the moon. While the barbarous natives around them beat their breasts and cried to their gods, those messengers of the enlightened world were observing the changing appearance of the solar halo. They waited for the moon just to cover the sun to the rim. Immediately a number of stars burst into view; the shutters of their cameras clicked; and their photographic plates were exposed. Directly they hurried to dark rooms to develop their plates. As the plates were being washed in the photographic solutions, several black dots made their appearance indicating the

positions of the stars. Soon, expert hand identified those spots, and their relative positions were compared with those obtained when the sun was nowhere in the neighbourhood. The stars at the fringe of the sun were found to be deflected from their normal positions according to Einstien's prediction. What Einstein conceived mathematically was thus proved by experiment.

When a scientific prediction is made without indicating proper methods of verifying it, scientists are at a loss to find out where and how to seek for the predicted phenomenon. Then it may so happen that the prediction is verified by men who, in the course of investigating their own problems, come across the predicted phenomenon under circumstances not indicated by the prediction. The discovery of Raman effect is an instance in point.

*Certain revelations regarding the nature of light, and the internal structure of atoms and molecules, come to light in recent years, indicated that a beam of light of a single colour should give rise to new colours, when passed through a suitable medium. A ceriain physicist worked out the idea mathematically, and derived an equation to represent the change in colour. The logic by means of which the conclusion was arrived at was so rigid, the mathematics so faultless, and the starting data so well-estabiished, that the prediction appeared to be quite sound in every respect.

*Planck's Quantum Theory as applied to light by Einstien and the Theory of electronic orbits as developed by Bohr and others.

There was, however, one flaw in the prediction; for it left the physicists in the dark regarding the conditions under which the phenomenon might be observed. Though quite a number of physicists began to search for the new phenomenon, none of them succeeded in their endeavours. The honour of witnessing the phenomenon for the first time fell on Sir C. V. Raman, while he was investigating a problem of his own. He had long been working on his favourite subject of the scattering of light by liquids. During the course of his experiments, he came across an interesting phenomenon, which on systematic study was found to be just the one so many physicists were searching for all the time.

A beam of sunlight stealing into a room through some hole in the roof is a common sight. We are able to see the path of the beam, because the dust particles floating in the air scatter the light in all directions. If a glass of turbid water is placed across the path of the beam, the same phenomenon may be observed. Here it is the fine particles suspended in the water that scatter the light. If a transparent liquid free from any suspended impurities is now substituted, the light scattered will be very feeble; but it can be detected easily by performing the experiment in a dark room, and the track of the light can even be photographed. Here the light is scattered by the invisible molecules of liquid.

An interesting feature of this phenomenon is that even when a colourless liquid is used and

the light passed through is white, the light scattered shows a sky-blue colour. It is a well known fact that white light is a mixture of various colours so proportioned as to produce the sensation of whiteness in our eyes. If a beam of white light is passed through a glass prism, several beams each of a different colour will be seen emerging from the prism. If now the several beams are brought together the resultant light will be white. But if one or more of the component colours is withheld the resulting beam will be coloured.

Coming back to scattering, it is found that the molecules of a liquid can scatter the blue rays present in white light more easilythan the other components. If, therefore, a beam of white light is passed through a liquid, while most of the colours pass on straight, the blue component undergoes partial scattering. Hence the light scattered by the liquid shows a blue tint. It was on this principle that Sir C. V. Raman gave for the first time an acceptable explanation of the blue colour of the sea. Sea-water is able to scatter the blue component of white day-light passing into it much more than the other components. It is owing to this scattered blue light coming from the depths of the sea that it appears to be blue.

It is clear from the above discussion that, if a beam of light made up of different colours is passed through a liquid, it is possible for the scattered light to be different from the incident light; for only some of the colours may be scattered while

the others pass on straight. If, however, a beam of light of a single colour which cannot be broken up into simpler colours is passed through a liquid, any light which it scatters should be only of the original colour. Some of the experiments of Sir C. V. Raman seemed to call in question the above principle. He observed certain strange colour changes produced by scattering. They could not be explained by supposing that some of the colours of the incident light were selectively scattered by the molecules of the liquid. He obtained, for example, greenish-blue light by passing a beam of violet light through a liquid. Physicists knew very well that violet light did not contain any green or blue component in it. Then were did the latter colours come from?

While reflecting on the possible reasons for these changes of colour, it occurred to Professor Raman that a similar phenomenon had already been observed in the field of X-rays. X-rays, by the way, though far more penetrating that light and invisible to our eyes, are really of the same nature as ordinary light. Just as there are lights of different colours, there are different varieties of X-rays which by analogy may be called "colours". The discovery referred to above was that X-rays of a single "colour" gave rise to new "colours" when scattered by certain substances. Dr. Raman thought that what was true of X-rays might as well be true of ordinary light, and he proceeded to verify the suggestion.

To study the change of colour systematically, it was necessary to work with simple elementary colours. Professor Raman found that light-rays of sharply defined colour were emitted by the vapour of mercury, when it was made to glow in a special lamp. Arrangements were made to examine this light before and after it was scattered by a liquid. The apparatus which he used could single out the various colours of the scattered light, and enable them to be seen in a dark room or registered on a photographic plate. When all arrangements were ready, he performed the experiment with a suitable liquid, and photographed the scattered light. He found that, though the incident light contained only a single elementary colour, the scattered light showed new colours along with the original colour. Now it became clear to Professor Raman that the phenomenon already shown to exist in the field of X-rays has an analogue in ordinary light.

Dr. Raman did not stop there. He would study the subject quantitatively and measure the variation in colours. He calculated the relationship between the colour of the incident light and the colour of the scattered light. He remembered how it had already been predicted that it should be possible for light of a single colour to give rise to new colours. He remembered, too, the mathematical equation given, according to which the change of colour was to take place. He compared the results of his observations with the predicted equation, and was delighted to find that they

agreed exceedingly well. The theoretical prediction was thus experimentally verified by Sir C. V. Raman, though he arrived at the result independently of the prediction.

Professor Raman was quick to realize the significance of his discovery. On continuing the experiments with different liquids, but with light of the same colour, he found that the new colours scattered by different liquids were different. In fact each liquid altered the colour of the incident light in its characteristic way. Since the ultimate agents bringing about the scattering were the molecules of the liquid, the scattered light should bring some tidings from the little-known world of molecules. He compared the colour of the light entering the liquid with the colour of the scattered light emerging from it. The difference between the two depended on the structural details of the molecule and so gave him an insight into some of the intricacies of molecular architecture. An invaluable weapon to probe into the mysteries of invisible molecules was thus discovered. The scientific world in recognition of the achievement of the Indian scientist, named the new phenomenon "Raman effect."

The above examples amply illustrate the remarkable part played by theoretical predictions in the advancement of scientific knowledge. But for the predictions the discovery would have been indefinitely delayed or never made. No physicist would have pierced the forests of south America

to see whether light was attracted by matter, if the idea had not been given beforehand by Einstein. Nor would Hertz have groped about in his laboratory with a loop of wire to detect "wireless" waves, if Maxwell's equations had not predicted them. It is not only by performing experiments, and observing actual facts, that new truths are discovered. Abstract ideas and mathematical symbols may occasionally lead to remarkably novel truths which, when verified by actual observation, go straightway to enrich the treasurers of the realm of science.

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CHAPTER XI

REVELATION OF TRUTH IN A FLASH.

No account of methods of discovery would be complete, without a mention of the subtle and mysterious revelations of truth, which flash on occasion across the minds of scientists. When experiments cease to bear fruit, when reasoning and calculation do not take the scientist any further, and when he is driven to the end of his resources, the solution of a problem sometime flits across his brain, he knows not how. All on a sudden, the mind glows with the long-looked-for solution. A moment ago, he stood bewildered as before the sphinx. Now the scales have fallen from his eyes and the riddle lies bared of its mystery.

Archimedes was court inventor to the King of Sicily in the third century B. C. Once the king entrusetd Archimedes with a tough problem to solve. He had ordered a crown of pure gold to be made for him. When the crown arrived, he grew suspicious that the goldsmith had mixed some silver with the gold. Archimedes was asked to devise a method of testing whether there was any silver in the crown, without damaging it in any way. The great inventor immediately set to work on his arduous task. He thought and thought, but could not find out a solution to the problem. One evening, it so happened that, on stepping into a tub full of water for bathing, he felt as if his body

became very light under water. Suddenly the solution of the vexed problem darted across his brain. The idea came to his mind like a flash of lightning, and like a flash of lightning he bounced out of the bath, and ran through the streets, all wet and stark naked, crying, "I have found, I have found." Every passer-by mocked at the absent-minded inventor; but now every first year student of physics has the name of the celebrated physicist on his lips.

The big idea that he discovered was that, when a body is immersed in water, it loses part of its weight. Two bodies of equal weight and of the same material should undergo the same loss of weight. The losses of weight sustained by two bodies of equal weight but of different materials should, on the other hand, be different. So if a ball of pure gold equal in weight to the crown were weighted under water, it should sustain the same loss of weight as the crown. If the crown contained a light metal like silver alloyed with the gold the loss of weight would be much more than that sustained by the golden ball of equal weight. When Archimedes performed the experiment, he found the loss of weight of the gold crown in water to be much greater than that of an equal weight of pure gold. So it became clear that the crown was an alloy of gold and a lighter metal. The king was convinced of the fraud and the goldsmith convicted. Archimedes had often stepped into baths and, probably, felt his body light too. But never

did it strike him that it demonstrated any scientific principle. But now all on a sudden the truth dawned upon him. There was no tedious calculation or reasoning. The revelation was simple, direct and instantaneous.

E. Howe was an American mechanic, who conceived the idea of a machine that would do the work a seamstress One by one he mastered all the difficulties, and constructed a machine which had only one defect about it, that it did not sew. That was woefully depressing indeed. A sewing machine which did not sew could only be an object of derision. All his labours seemad to have been in vain. Neither his mechanical skill nor his inventive genius could solve the problem. Nevertheless he kept on pondering ever it.

The story is told how one day, worn out and utterly disheartened, Howe fell asleep and dreamed that he was sentenced to be hanged for being unable to perfect his machine. As the guards were leading him to the place of execution, he noted that the points of their spears were pierced with holes. It flashed through his mind, that he should pierce the needle of his machine not at the head as was the custom, but at the point. When he put this idea into practice the machine worked perfectly well. This was the precursor of the modern sewing machine. Whether the story of the dream is true or not, nothing less than a revelation would have suggested to Howe the idea of piercing the needle at the point when ordinary

needles had their holes at the head.

The name of James Watt will ever be remembered in connection with the evolution of the steam-engine. That the power of steam can be made use of to produce mechanical motion was known for a long time. The type of steam-engine in vogue in Watt's time was crude and inefficient. Steam produced in a boiler when admitted into a metallic cylinder lifted up the piston. Then the steam was suddenly cooled by injecting cold water into the cylinder, the supply of steam from the boiler being cut off simultaneously. As the steam was condensed when cooled, a partial vacuum was created in the cylinder. Now the pressure inside the cylinder being reduced almost to nil, the presure of the atmosphere from above forced down the piston. Then the steam was again admitted and the process repeated. The up-and-down movement of the piston was utilized to work a water-pump through the agency of suitable levers.

By a careful study of the engine, Watt was able to lay his fingers unerringly on its main defect. He realized the seriousness of the enormous amount of heat wasted during the cooling process; for the injection of cold water cooled not only the steam but also the containing cylinder. When steam was next admitted, much of its heat was wasted in reheating the cylinder. It was essential to cool the steam efficiently, to obtain the maximum vacuum. It was equally important to keep the

cylinder always at the temperature of steam, so that none of the heat of the steam was lost in re-heating the cylinder. How to cool down the steam, and at the same time keep the temperature of the cylinder constant, was the problem that engaged the attention of the young engineer.

The solution of this puzzle occurred to James Watt while he was strolling in his garden one fine afternoon. In his own words, the idea flitted across his brain, when he had "gone as far as the herd's house". Yes, the cylinder can be permanently kept hot, and still the steam cooled, by using a separate vessel permanently kept cold, for condensing the steam. If this vessel is put in communication with the cylinder when the latter is full of steam, the steam will rush into the cold vessel, and get condensed immediately. Since the steam gets condensed as soon as it enters the vessel, it will always maintain a low pressure. Hence the steam will rush into it, whenever it is put in communication with the cylinder. This was the main feature of the improvements effected by James Watt on the crude steam-engine of his day. He used a separate condenser, instead of condensing the steam by introducing cold water into the cylinder. And the idea occurred to him all on a sudden during a ramble.

When a chemist comes across a new compound, he invariably attempts to derive the structure of its molecules. He has to resort to indirect evidence for this purpose, since molecules are too small to

be seen. Chemists have long been familiar with natural oil, which gushes out of the depths of the earth in various parts of the world. Natural oil is an important commercial commodity, as it is from it that valuable oils like kerosene and petrol are obtained. By a study of their properties, chemists came to the conclusion that the molecules of these oils consist of long strings of carbon atoms, each carbon atom holding in addition two or more hydrogen atoms. The molecules of the different members of the natural oil family, like petrol and kerosene, differ merely in the length of the strings.

When later, chemists discovered benzene, an oil resembling natural oil in many respects, they began to wonder what the constitution of the benzene molecule might be. Analysis showed that it contained only carbon and hydrogen, like the natural oils. But some of the properties of benzene were found to be markedly different fron those of natural oil. The difference in properties between two compounds is sufficient indication for the chemist to infer that their molecular structures also should be different, even though they may happen to be built up of the same elements. Hence it was clear that arrangement of the carbon and the hybrogen atoms in the benzene molecules should be different fron that in the natural oil molecules. Chemists, however, could not suggest what the difference was. The constitution of benzene becane a great problem, and many minds were engaged in trying to solve the mystery.

Kekule was a German chemist very much interested in the benzene problem. One cool evening, while riding on the top of a cab along the streets of Berlin, he was so much engrossed in the puzzle that he became oblivious to what was happening around him. The hurly-burly of the traffic, or the hoarse cry of the pedlars, did not divert the attention of the absent-minded chemist. His mind was enwrapped in the structure of benzene. As atoms and molecules are invisible, he pictured before his mental eyes long strings of carbon atoms as in the natural oil molecules. The strings in the vision writhed and wriggled like serpents In the turmoil of these pulsating motions he saw the heads of some of the serpents bending round and swallowing their own tails; and the circular figures formed thus whirled mockingly before his eyes. Kekule saw in a flash the solution of the benzene problem. Whereas the natural oil molecules consist of strings of carbon atoms, the benzene molecules are made up of rings formed by bringing the free ends of the strings together.

While the chemists were collecting data, systematizing, analysing and correlating them, the happy idea flitted across Kekule's brain in a fanciful image. The constitution of benzene has since turned out to be of the utmost significance. Today, the number of useful substances such as dyes, perfumes and medicines, that have been built up from benzene and its relations is a legion; and the foundation of the synthesis of all those compounds

is the structure of the benzene molecule, which flashed across Kekule's mind on the top of a Berlin car on a cold wintry evening.

Mysterious are the ways in which truth reveals itself. When faced with a tough problem, scientists set up elaborate experiments, observe facts minutely, and systematize their observations. They try to find out a solution for the puzzle by logical reasoning and mathematical analysis. The problem is attacked from different directions and in diverse ways. They argue and reason; they generalize facts and deduce inferences. But the problem may seem none the less baffling for all their endeavours. When at last they reach their wit's end, the solution may dawn upon the mind of a thoughtful investigator all on a sudden in a strange and inexplicable way. It is like being hoisted up a tall tower in an electric lift with lightning rapidity, when others are painfully struggling their way up the devious stair-case.

CHAPTER XII

FINDING THE WAY BY GROPING IN THE DARK.

Imagine that a gruesome murder was committed in your town, and that the murderer has escaped. Imagine also that you are the detective inspector appointed to investigate the case. There are two ways of going about the business. You may suspect every person who had anything to do with the deceased. All his friends, relatives, colleagues and acqaintances, are kept under the strictest observation. Their houses are examined, and themselves subjected to a volley of searching questions. You may get all your assistants to watch their movements, and overhear their conversations. If such an exhaustive inquiry is made, no villain however clever may escap detection.

The other alternative before you is to study in detail the circumstances under which murder was committed. You collect all available information about the habits and tastes of the deceased. An inquiry is made whether any of his acquaintances is likely to be benefited by the murder. The probable course of events that led to the murder slowly takes shape in your mind. All your suspicions centre round three or four persons; and you confine your inquiries to these alone. As you proceed in your investigations, some of your suspicions are strengthened, while others appear more and more groundless. Working like this you hope to detect the murderer sooner or later.

The latter method is obviously the more sensible of the two. It appears midsummer madness to keep an army of police men to spy on hundreds of innocent citizens. Nevertheless, at times one has to follow such a procedure. For, it may so happen that your guesses are all wrong. Perhaps the murder was actually committed by a close friend of the victim.

If you confined your investigations to the few persons whom you suspected, there was little chance of your coming across the real murderer. Not because there was any flaw in your procedure. For, in the light of facts which you were able to gather, your guesses were quite sound. Nor are you to be blamed for not suspecting the friend. Who would imagine that an intimate friend would be guilty of such a crime? In fact it would appear absurd if you suspected him. You were perfectly right so far as you went. But you did not know enough. So your theories led you astray. If you were aware of any reason to suspect the friend, you would certainly have worked up the clue and solved the mystery too. In the absence of any such clue the best way to hit upon the real culprit was to suspect every person who had anything to do with the deceased, absurd though the procedure might be. The reasonable path is not always the right path to discovery.

The scientific method of attacking a problem consists in gathering all the relevant facts, and connecting them together into a coherent system.

The possible solutions of the problem suggest themselves to the scientist's mind, and enable him to confine his investigation to a few regions, where the solution of the problem may reasonably be expected. He tries the various possibilities one by one, each failure throwing new light on his path. Proceeding like this, he hopes to arrive at the truth. Sometimes, however, it may so happen that the solution may be lurking in such unexpected corners, that the scientific scheme may not be comprehensive enough to embrace it at all. While dealing with such problems, reasonable methods are of no use; for they lead to blind alleys; and common-sense seems to play one false. It is here that the capacity of a scientist to rise above and soar away from accepted modes of thinking stands him in good stead. Some workers even do away with any preconceived scheme. They explore every by-way and lane they come across, and examine every nook and corner, without ever reflecting on the reasonableness of their procedure. The scientific investigator will not be surprised if sometimes the unscientific worker overtakes him in the race. The capacity to get out of the grooves of reasonable thinking is a virtue in a discoverer.

Thomas Edison is the supreme example of an investigator working without any scientific scheme. He rode roughshod over time-honoured methods of research. Haphazard trials till success was his motto. Once he set one of his assistants to prepare a suitable wax to be used in the manufacture of

gramophone plates. Another chemist had already done some work in the field. Naturally the newcomer requested Edison to furnish him with the notes of his predecessor. Edison flatly refused to do anything of the kind. He wanted the new man to pursue his own methods instead of being prejudiced by the results of his predecessors. The unfortunate assistant thus left to himself began to attack the problem starting from the very beginning. After working for a few months, the assistant got dejected and approached Edison with the remarks: "I have no hope of succeeding. I have tried all reasonable methods. We had better give up the problem for the present." "There you are, my boy", retorted the veteran inventor. "It is just what I want. Reasonable things don't work. Now you go and try unreasonable methods."

While trying to harness electricity for lighting purposes, Edison discovered that when a current of electricity is passed through a filament of carbon placed in an evacuated glass bulb, the filament glowed emitting a brilliant light. He prepared the carbon filament for this purpose by charring vegetable fibres. Finding that the fibres available in his own country did not quite suit his purpose, he sent an army of explorers all over the world to find out a suitable fibre. And the funniest part of the story is that, while those enthusiastic inquirers were fighting with wild beasts and mosquitoes in the heart of Amazonian and Japanese forests, the great inventor changed his mind and decided to

use some other substance for his lamp. A scientific investigator in his place would have studied the subject exhaustively, and confined his investigations to reasonably sound fields.

Once he wanted to construct a crushing machine to break into powder a rocky mineral. After tedious calculations, his engineer prophesied that the kind of machine that Edison had in view would never work. Edison threw the engineer's science to the winds, and made the machine, and crushed the rock too. He never believed in the scientific method, though he made free use of the facts of science for his inventions. He hated everything academic, and weaned his assistants' minds for all scientific theories. Few of his multitudinous inventions were the results of theoretically sound modes of research. "How singular," remark a writer, "that Edison, the 'Wizard of Invention', never made a scientific discovery in his life." He worked helter-skelter and stumbled on his inventions.

J. Priestley used to take an absorbing interest in experimenting with chemicals. Having come into possession of a big burning lens, he proceeded to heat different kinds of substances by concentrating the heat rays of the sun on them. To see whether any gas was evolved during the heating, the substance was confined over mercury in a jar inverted in a trough containing the same liquid. He took his apparatus to the open air, and heated the substance with the aid of his burning lens. He

used every substance that came into his hands for his experiments.

One of the substances he tried was a red powder called mercuric oxide. As the heat rays of the sun were being focussed on it, Priestley observed with pleasant surprise that the level of mercury was falling down rapidly in the jar indicating the formation of a gas. Those were days when very little was known about gases. Wondering whether it was ordinary air or some new gas, he introduced a burning candle into it. He was astonished beyond measure at the dazzling brilliancy with which the candle burned in the gas. He breathed it and felt an exhilarating sensation. Obviously it was not ordinary air. He had discovered a new gas, which was later called oxygen.

The object of Priestley's experiments was to find out whether any substance evolved a gas on heating. He did not know which type of chemicals would suit his purpose. So he tried every substance that came into his hands. His investigations were haphazard trials. Yet the results of his experiments made a solid contribution to the progress of chemistry.

The marvellous use of chloroform in modern surgery is known to all. Before its discovery, surgical operations were associated with pangs of pain and a sense of desertion and despair. What was once a terrible ordeal attended with unbearable pain now passes off, with the patient blissfully unconscious of the butchery carried

on his person. The surgeon, no longer dreaded as an unavoidable evil, has thrown the physician to the shade. Before the discovery of chloroform there were a few chemicals known as anaesthetics which when administered to patients rendered them temporarily unconscious. There were, however, many difficulties in their use. They were too disagreeable and irritating to the patients; and sometimes the patient recovered consciousness in the middle of the operation.

A young Scotch doctor, J. Y. Simpson by name, had too tender a heart to stand the groans of suffering patients during operations. He determined to discover a new anaesthetic which would be quick in its action, and would retain its effect for a sufficiently long time without any injurious effects on the body. The field of research was entirely new. There were no principles known, by which he could expect which liquid would serve his purpose, and which would not. So he proceeded to experiment with every liquid that came into his hands.

Simpson collected all the liquids known to chemists, and stored them in his house. Night after night, he used to open the bottles one by one, breathe in the contents, and note the effect on his system. On the night of the 4th November 1847, he was engaged as usual in the dangerous quest after the ideal anaesthetic. He had also with him some of his friends and assistants. Having breathed in several liquids without any sensational effect, it

flashed through his mind that he had left a colourless liquid on the lumber-table. Though he had come into possession of the liquid some-time earlier he had left it aside as he thought it to be of no use, on account of its heaviness. Now, however, he decided to try that too. The heavy liquid was immediately searched for, recovered from the lumber, emptied into glasses, and divided among the party.

As the vapours of the colourless liquid were being inhaled by the would-be discoverers, they were seized with a hilarious vivacity. They burst into voluble effusions about the delicious aroma of the liquid. Gradually the lively speeches gave way to a roaring snore like a distant rumbling of thunder. Soon all was quiet; and then a series of thudding sounds of crashing bodies disturbed the silence. On regaining consciousness the first thought that passed through Simpson's mind was that the heavy liquid was more efficient and safer to use than anything he had tried before. The second thought was that he was lying postrate on the floor, and the third that his friends' positions were no more elevated nor less ludicrous than his own.

It was thus that the anaesthetic property of chloroform was discovered. A funny made of making discoveries indeed! Simpson was like a man who gropes in the dark to reach the door, and bumbs against the wall again and again before he finds the way out. It was not long, before Dr. Simpson actually used chloroform as an anaesthetic

and demonstrated to the world its marvellous use in surgery. Chloroform came to be increasingly used in hospitals. Much opposition was first raised to its use in child-birth. But when Queen Victoria took chloroform in one of her confinements that barrier also was removed. And now chloroform has become the indispensable handmaid of surgery, all owing to a kind-hearted doctor monkeying with volatile liquids.

Many important discoveries were the results of haphazard trials. All the same, it cannot be recommended as a sound method of research. For one has to pay dearly to attain truth by trying every idea that occurs to one. Though each failure adds to the experience of the investigator, the time and energy wasted on it are out of proportion to the gain. Many such failures may be avoided by working in the light of scientific theories. And yet when working in a new field, or when scientific knowledge about the subject is not illuminating enough, the haphazard worker often gets the better of the scientific investigator. The trial and error method though costly has a place in research. It is a useful weapon to probe into the mysteries of Nature, when other methods fail.

CHAPTER XIII

ACCIDENTAL DISCOVERIES.

Sometimes the dark and weary path of an ardent investigator is lit up by an accidental revelation of some new truth, which, though not the one he has been working for, turns out to be of no less significance. Nothing more romantic can be imagined in the realm of scientific discovery than the sudden light that gleams before the eyes of a despondent worker, unveiling new facts, or opening up fresh fields of research far and away from the sphere of his labours and the scene of his lost battles. Columbus discovered America on his perilous voyage to the domain of Kublaikhan. He never reached Asia by going round the world; and even if he had, the route would have been of no use for European sailors. Sir Walter Raleigh explored the wastes of South America in search of Eldorado, the mythical land of glittering gold mines. Eldorado, of course, was none the less mythical for his adventurous invetigations. But he discovered the asphalt lake of Trinidad, which has since been, in effect, a mine of gold for enterprising people. For, thousands of tons of asphalt are exported from Trinidad to the various ports of the world, bringing enormous wealth to the owners of the concern.

The element phosphorus is famous by reason of its easy inflammability and its use in the manufacture of matches. When it was first discovered

it was a curiosity, guarded with the utmost secrecy, and exhibited only in royal courts. Those were days when all the labours of chemists were directed to the discovery of an imaginary substance called the philosopher's stone, which was supposed to have the virtue of converting base metals into gold. In this mad chase, they explored the mineral, vegetable and animal kingdoms, and heated, distilled and burned, whatever came into their hands. One of these gold enthusiasts, Brand by name, happened to distil a mixture of sand and urine. We can imagine the old chemist greedily looking for the appearance of the mysterious philosopher's stone. As he was heating the mixture, a wax-like substance made its appearance. On examination it was found to be a mysterious substance, indeed, though not the philosopher's stone. It glowed in the dark, and caught fire on rubbing against the floor. Brand had stumbled on phosphorus, in his wild-goose chase after the philosospher's stone.

The beautiful colouring powders sold in the market as aniline dyes are familiar to all. The discovery of the first aniline dye is one of the most thrilling in the history of chemistry. An English chemist called Perkin was studying the effects of various chemicals on aniline, in the course of his attempts to synthesize quinine. During one of these experiments the temperature rose too much owing to oversight, and the whole mixture frothed up into a black mass. Thinking that the compound

he was looking for was destroyed by the overheating, he threw the whole mass into the sink, and hastened to start a fresh experiment.

Next day, however, when he opened the water-tap, he was surprised to find the water falling on the black stuff assuming beautiful hues. The discarded stuff was immediately reclaimed, extracted with water, and the colouring matter isolated. On examination the substance was found to be a very beautiful dye. While trying to synthesize a useful drug, Perkin had stumbled upon the method of synthesizing a useful dye. The significance of his discovery can hardly be overestimated. Close on the heels of this historic experiment, others followed producing newer and better dyes. And now the market is flooded with thousands of dyes of diverse shades, satisfying the delicate tastes of the feminine world.

Not very infrequently, casual incidents have been the means of revealing new truths of great importance. *Galvani, an Italian scientist of the eighteenth century, used to do his experiments in the pantry for want of a better room. Frogs were a special delicacy of the house. One day Mrs. Galvani had a number of frogs' legs hung up in the room to be got ready for dinner. Galvani was working an electrical machine with an occasional glance on his prospective dinner.

* Different versions of the story are current. It is not presumed that the details of the discovery given above are historically correct. The fact remains, however, that the discovery was accidental.

He was surprised to find that, whenever he happened to touch the legs of a dead frog with a metallic knife, they gave a sudden twitch. It is said that after that, whenever a consignment of frogs arrived in the house, Galvani would raid the larder and make the dead frogs jerk and jump. Presuming that the leg muscles contracted owing to the discharge of electricity from the electrical machine, he wanted to see whether the same thing would happen during a thunder-storm, which was known to be a discharge of electricity from the clouds. With this end in view he hung up the legs on the terrace by copper hooks on an iron railing. A strong breeze was blowing ; and Galvani noticed that, when the legs were blown up against the iron railing, they began to twitch.

Such was the first observation of the production of an electric current. Before that they only knew how to produce and store electricity ; they did not know anything about electricity in motion. In Galvani's experiment, the two dissimilar metals in contact tended to produce a current of electricity, which passed through the flesh causing the muscular contraction when the legs touched the iron wire. When the legs were not touching the iron wire, the current did not flow, because the circuit was not complete. In fact Galvani had unintentionally made the first electric cell. He, however, did not understand how the current of electricity was produced. But one of his successors in the field gave the correct explanation for the

phenomenon, and constructed the first electric battery. He made it by piling discs of two dissimilar metals alternately, the metals being separated from each other by some moist fibre.

The decomposition of water by electricity is a well-known example of how trivial incidents bring about momentous discoveries. Two physicists, Nicholson and Carlisle, were performing certain electrical experiments. Once it so happened that the metallic wires from their battery came in contact with some water on the table. They were surprised to see a vigorous effervescence from the tip of one of the wires. On repeating the experiment, and collecting the gases evolved, they found them to be oxygen and hydrogen, the known components of water. Water had been analysed for the first time by an electric current. Till then the usual method of decomposing a compound was by heating it. Now the chemists were provided with a new instrument for the decomposition of chemical compounds. Substance after substance began to be decomposed by electricity. The manufacturer was quick to realize the economic significance of the new weapon. To mention but one example, the metal aluminium, which had to be prepared at enormous cost originally, could, after the introduction of the electrical method, be manufactured far more cheaply.

Sometimes, after a series of fruitless trials, a dejected investigator may find out the solution of his problem as a result of some accident. When

the German chemists were attempting to synthesize indigo, the problem was attacked from different directions. Of the many methods suggested, one started from phthalic acid. But owing to the high price of phthalic acid, the method did not find any commercial application. Then it occurred to the chemists that naphthalene was closely related to phthalic acid in the structure of its molecules. Naphthalene, by the way, is known to everybody in the form of white balls used to scare away book-worms. Encouraged by the cheapness of naphthalene, attempts were made to convert it into phthalic acid. With this end in view, they treated naphthalene with various chemicals under varying conditions.

In one of the laboratories naphthalene was being heated with sulphuric acid in different flasks under different conditions, a thermometer being inserted in each flask with a view to regulating the temperature. When the experiment was over, the chemist in charge began to analyse the contents of each flask to see whether any phthalic acid was formed. He noticed that in one of the flasks the thermometer was broken and the mercury spilt. We would forgive him if he got irritated over the mishap, and rebuked his attendant for his carelessness. But what the good chemist did was to analyse carefully the contents of the flask, when to his surprise he found that the naphthalene was almost completely converted into phthalic acid. The naphthalene in the other flasks containing only

sulphuric acid remained unchanged. What sulphuric acid alone could not do was accomplished with surprisIng facility in the presence of a little mercury. This provided the chemists with a cheap means of obtaining phthalic acid, from which indigo could be prepared easily.

Goodyear, an American inventor, was experimenting with rubber to make it harder and stabler. He worked on for years without the least promise of success. He had spent all his money on his investigations, and was already on the verge of bankruptcy. Yet he pushed on his researches with undiminished enthusiasm. During the course of one of his experiments he happened to work with a mixture of sulphur and rubber near a hot metallic plate. Some of the mixture accidentally fell into the plate. It hissed and fused, and ultimately gave a dark mass which on examination was found to be just the substance he was searching for all the time. He had stumbled on a method of vulcanizing rubber. And to-day millions of rubber-tyred vehicles proclaim the practical importance of his discovery.

Nobel, a Swedish chemist, was experimenting with the liquid known as nitroglycerine with a view to making it a useful explosive. Nitroglycerine, by the way, is a highly explosive liquid. Since it explodes at the slightest shock, it is too dangerous to deal with, not to speak of transporting it from place to place. Nobel tried several methods of making the liquid less dangerous without weakening its

explosive property. But a satisfactory process was not forthcoming. One day he happened to cut his fingers and apply some collodion over the wound to give it a protective coating. A little collodion was left over, and he just felt curious to know what would happen if collodion and nitroglycerine were mixed together. On adding the remaining collodion to a little nitroglycerine he obtained a jelly-like mass. Nobel proceeded to study its explosive properties, and was surprised to find that it did not explode as easily and dangerously as nitroglycerine, but was as powerful when it did explode. This was just what was wanted for blasting purposes. Nobel had accidentally discovered a safe explosive. The new product called blasting gelatine came to be used in ever-increasing quantities in breaking up rocks for making roads and tunnels.

It was the period immediately following the discovery of current electricity. Professors in various laboratories began to experiment with it hoping to disclose some of its mysteries. Oersted, a professor of physics, wanted to find out whether there was any connection between an electric current and the phenomenon of magnetism. He did not know how to go about the business. He tried many experiments, but without any success. Once it so happened that during the course of one of his lectures, he brought a suspended magnetic needle near a metallic wire carrying an electric current. He was surprised to find that the needle

was deflected from its north-south position through quite an appreaciable angle. This was the first demonstration of any relation between electricity and magnetism. It was not long before it was found that the phenomenon could be used for signalling messages from place to place. If a metallic wire was stretched between two stations, whenever an electric current was sent through the wire from one station, a magnetic needle placed near the wire at the other end was deflected. By deflecting the needle for shorter or longer periods, at short or long intervals, and by attaching definite meanings to each, messages could be transmitted acrosss the wire. This device was the precursor of modern telegraphy: and it was a happy accident that revealed the principle.

The tight-fisted hands of Nature relax on occasion, and confer her closely guarded secrets all on a sudden on her devotees. Nevertheless, she is not as eccentric as she would appear to be. She does not shed her secrets in generous profusion, for the research worker to bump against at every corner. Her favours are reserved only for those who are worthy of them. It is true that Raleigh discovered Trinidad accidentally; but it is also to be remembered that the idle stay-at-homes discovered nothing. Hidden treasures are only for those who dig deep in Nature's vineyard.

It is true that Goodyear discovered the process of vulcanization accidentally. But he came across the happy method only after years of fruitless

research even to the point of starvation. If the leap to fame and wealth of a pauper experimenter by stumbling on a great discovery appears romantic, the intensive research and persistent effort behind the thrilling discovery are no less edifying. It is, indeed, very interesting to learn that the modern dye industry originated from Perkin's accidental discovery of the first aniline dye. But the circumstances under which the discovery was made should not be lost sight of. Pekin was then working as a chemical assistant. After labouring all day long in his master's laboratory, he used to toil hard in the crude laboratory he had set up at home to find out a method for the synthesis of quinine. It was to such an ardent worker that the secret of the aniline dyes was first revealed. It was a consolation prize, as it were, to the unfortunate worker, though the consolation prize turned out to be more valuable than the one striven for and missed.

Accidental discoveries have played a remarkable part in the progress of science. Many a weary worker, though he never arrived at the goal aimed at, incidentally come across new facts which turned out to be even more significant. Occasionally a keen investigator met with success by a sheer accident, after a series of dismal failures. The new truths revealed were so novel and unexpected that it would have required years of patient experimentation and critical reasoning to arrive at them in the usual course. Accidental

discoveries are short cuts to truth. They have been few and far between, and the share of only the worthy. When such discoveries were made, however, scientific knowledge progressed by leaps and bounds.

CHAPTER XIV

VARIETIES AND LIMITATIONS OF GENIUS.

Accounts of the achievements of great men of science fill our minds with admiration for their genius. Lost in amazement, we may even exalt them to a world of unapproachable idealism and intellectual perfection. To tell the truth, even great scientists had their share of human frailties and intellectual shortcomings. They were not all bright luminaries far and away from ordinary mortals. Each of them had specific abilities of his own, often surrounded by a multitude of limitations and drawbacks. The secret of their success lay in directing all their energies to the solution of problems most suited to their tastes. From their successes we may infer the nature of their genius, and from what they failed to achieve their shortcomings. He who would advance the cause of scienec never pines for what he does not possess; but finds out his aptitudes and makes the best use of them. No man ever was great who did not seek to achieve much more than he was able to.

Flying has all along been the ambition of man. For years he had to content himself with drifting along in balloons. Then gradually the possibility of heavier-than-air machines rising up in the air dawned upon the mind of man. An American professor, Langely by name, studied in his laboratory the conditions under which a moving body could keep afloat in air. He found that the faster

a plane is moved through air, the less does it tend to fall down. This was a remarkable discovery; for, the known laws of physics did not provide for such a phenomenon. All the same, when he attempted to make a real man-carrying plane, this great professor who discovered the principle of the aeroplane failed ingloriously.

The first men who made a successful flight in an aeroplane were two brothers running a cycle repair shop in an American town. The Wright brothers, for that was their name, knew little physics. In fact they did not start from theoretical considerations at all. They had heard about the unsuccessful attempts of many to fly in gliders. By running off a gently sloping hill with the glider, people could raise themselves from the ground and glide down slowly through the air. A series of fatal accidents in gliding reported in the papers stimulated the interest of the young cycle repairers. They remembered how they used to play in their childhood with a toy made of paper, cork and bamboo. It was supplied with propellers, and was operated by a spring. When released it dashed upwards and rose to a fair height. They had also watched birds in their flight, and become familiar with every motion of their wings. Why should not man fly when birds and even toy-planes do? They wondered why others who were attempting to fly failed again and again. They decided to find out the cause for themselves.

The Wright brothers made a glider of their

own, and took it to a suitable place. Things were not so smooth as they had expected. They had to face immense odds ; but each failure helped to improve their glider, and to make themselves more efficient fliers than ever. Once so many things went wrong that one of the brothers said, "Man will never fly in a thousand years." After a time when he recovered his spirits, he corrected himself, "I meant man will not fly in fifty years." After many years of unsuccessful attempts, they could manage to take off from the ground and fly for a few hundred feet.

Then the brothers attached a petrol-engine to their glider. No longer had they to run downhill to get the initial speed for flying ; for, the engine worked the propellers and lifted the glider forward. This was the first aeroplane ever made. They continued to improve their machine;and it was not long before they could fly a few miles at a stretch. It was a wonderful achievement and the whole world resounded with the news. Everybody hailed it as a remarkable invention with marvellous potentialities. And the two cycle repairers were the pioneers in the field. The professor who conceived the idea had to leave it to the practical man to transform it into a machine of utility to mankind.

Every one associates the name of Marconi with wireless broadcasting, and some take him to be its originator. But it was not Marconi who discovered the principle of transmitting messages without wires. The "electric" waves made use of in all kinds

of wireless transmissions were predicted by the mathematical genius of Maxwell and shown to be actually producible by the experimental skill of Hertz. The possibility of using these waves to transmit messages from place to place was soon recognized and widely exploited. Instruments were devised to produce powerful "electric" waves, as well as to receive them. But these could work only within a range of about half a mile. What Marconi did was to make it work across the Atlantic by improving the instruments. The practical genius of Marconi converted a laboratory curiosity into a morvellous means of communication between continents.

Tycho Brahe was a celebrated astronomer who observed the positions of planets for twenty-five years. His patience was infinite, and the accuracy of his measurements marvellous. Nobody before him had gathered such a wealth of astronomical information. But his genius stopped there. He could not make head or tail of the maze of facts he observed. It was the systematizing genius of Kepler that wove the complicated threads of Brahe's observations into the three laws of planetary motion, Kepler, however, tried in vain to discover the cause of the harmony revealed by him. It remained for Newton to come forward with the Law of Universal Gravitation to explain not only Kepler's laws but all celestial motion. Each of these astronomers had his own genius unfolding itself in its own way.

Frenchmen adore Lavoisier as the founder of the science of chemistry. Yet this great pioneer, at one stage of his research on the cause of rusting and burning, was brought to a standstill. He had shown by experiment that when a metal was heated in air, it absorbed a portion of the air and was converted into an ash. The residual air no longer allowed substances to burn in it. He presumed that the metal had removed from the air something which was responsible for causing substances to burn. But he could not say what that something was. He racked his brains to find a solution to the problem but in vain. So he discontinued his investigations on the subject, and proceeded with his other experiments.

One day he happened to meet Priestley, the English chemist, at a dinner party in Paris. From him Lavoisier heard for the first time about the discovery of oxygen. Priestley told him that, when the red ash formed by heating mercury in air was heated to a higher temperature, it gave off a gas in which a candle burned with dazzling brilliancy. At once it flashed through Lavoisier's brain that it might be this gas that he was looking for so long, and that it might be the part of air that was responsible for burning. The hot mercury should have absorbed the gas from the air, and expelled it again on stronger heating. He rushed home, and repeated Priestley's experiment. He collected the new gas, and mixed it with the

inactive gas left over after the rusting of metals in air. To his great delight the mixture was found to behave exactly like ordinary air. Now he could clearly make out that air consisted of an active part, which he called oxygen, and an inactive part known later as nitrogen. When substances were burnt in air, they combined with the oxygen leaving behind the nitrogen. The English chemist by his hit-and-miss method had to stumble on oxygen first, before the great French chemist could give an explanation for the phenomenon of burning. Science like a wise employer makes use of the distinctive abilities of all her devotees.

Lord Lister will ever be remembered with profound gratitude as the founder of aseptic surgery. Thousands of soldiers wounded in battles and millions of victims of the surgeon's knife do him homage in silent salute. But what did this man Lister discover? Carbolic acid and its antiseptic properties had been known for long. The cause of the putrefaction of wounds was discovered by Pasteur. What Lister did was to find out by a series of experiments the conditions under which a solution of carbolic acid could be used to kill injurious microbes without irritating the flesh. It may also be mentioned to his credit that he introduced a special kind of bandage for wounds intended to prevent the entry of any germ from the air. What he did was to apply the discoveries of others to solve a pressing problem of the day.

Dalton, the great English chemist, was blessed with a vivid imagination and a genius for generalization. It was he who originated the Atomci Theory, the theoretical foundation of chemistry. And yet he was the crudest of experimentalists. The values he got in some of his experiments were so incorrect that, if a first year student of chemistry obtains them now, he would get a scolding from his professor. Nevertheless, with his crude methods Dalton discovered laws which escaped the most skilful experimentalists of his day. He had his own talents and he made excellent use of them for the advancement of science.

Michael Faraday, the great English physicist, knew little mathematics. To tell the truth, he knew less mathematics than any physicist of renown. His discoveries were the results of carefully planned experiments. He did not properly understand the mathematical implications of his discoveries. It was only by a mathematical treatment of the principles brought to light by Faraday, that the subject took a new turn after him and revealed the inner relationship of light, magnetism and electricity. Faraday's genius lay in devising experiments and making inferences. He was so much absorbed in giving expression to his genius, that he was hardly conscious of the drag on his success due to his lack of mathematical insight.

Nor were scientists faultless in their work. When we hear about the wonderful achievements of great men of science, little do we realize the

blunders and failures behind the curtain. The romantic discovery of potassium by Davy, and how he danced about the room for sheer joy, are described in text books. But how the same Davy went laboriously through fire and water to bring to the light of day other metals like calcium and aluminium, but failed, is not sufficiently known. The same Sir Humphry Davy had the temerity to publish certain papers regarding the chemical nature of oxygen and sulphur, which, to-day, even an elementary student of chemistry would criticise. It was this great chemist, again, who condemned the theory of atoms as a "tissue of nonsense"—a theory that has since been established as the bed-rock of chemistry. It is said about Priestley, the discoverer of oxygen, that he made so many mistakes in his work, that it was necessary for him to invent the use of India-rubber as an eraser in order to set them right.* Even the marvellous Newton, who stood head and shoulders above his contemporaries, was not free from faults in his work.

Many great scientists were not brilliant students. It is said of Charles Darwin that few men of his eminence were less brilliant than he. Nobody dreamt that he would attain such greatness as he did. When he finished his school career, he was sent to the medical college, which he left in a few months. Then he tried divinity with no better results. He managed, however,

* Sir Philip Hartog who has made a study of Priestley's life and work told author that this statement is unfair.

to get a degree from Cambridge but was tenth among those who did not seek honours. Then, while idling away his time collecting beetles, he was invited to accompany a surveying expedition round the world. It was what he observed during that voyage, which lasted for five years, that decided his life-mission, and impelled him to dedicate his life to biological research.

During his world tour and later on at home, he had to lead a secluded life owing to ill health. The calm solitude of his country-home afforded him an agreeable atmosphere for reflecting on scientific problems, and inspired in him those original and suggestive ideas which stood him in good stead in his great work. He had also a remarkable aptitude for generalizing facts and making unprejudiced judgements. He made such effective use of his talents for solving the mystery of organic evolution, that he became its most powerful exponent. It is said that "The Origin of Species" embodying the major part of his work was the book that created the greatest intellectual stir in the nineteenth century. That a tenth-rate Cambridge graduate could achieve it bears ample testimony to the power of science to bring out the best in man.

When Frenchmen were once asked to name their greatest countrymen, they mentioned the name of Louis Pasteur first. There is no man who has earned such a wealth of praise and reverance in the field of hygiene as this French chemist. It

is not a nation or a profession, but the whole world, that has been benefited by his work. All the same, the certificate he got from his school contained the remark, "Mediocre in chemistry". His teachers could not discover any remarkable talents in him, except that he was studious. And that was one of the secrets of his success.

It is said of Sir Humphry Davy, the greatest scientist of his day, that during his school days he did not show any taste for scientific pursuits. Nor could his teachers testify that he possessed any special abilities. Thomas Edison, the American "Wizard of Invention," displayed such stupidity at school that his teacher remarked that Edison had a confused brain. When, however, these men came under the exhilarating influence of science, their latent talents blossomed out, and themselves blazed forth from obscurity to glory.

Even the great men of science blundered and struggled through their lives just as ordinary mortals. What differentiated them from the common run of men was their delight in unravelling the mysteries of Nature. Each had his own characteristic aptitude and method of work. Some were skilful experimentalists; while others observed things with searching eyes. Some of the scientists had a genius for discovering unity in diversity. The paths of some were lit up by occasional flashes of inspiration, while others evolved new ideas by reasoning and calculation. There were investigators who arrived at truth by systematic research,

and there were those who hit in every direction till they hit right. The makers of science are a motely throng. All types of mental faculties are represented there. Science makes use of the specific ability of every worker to establish her kingdom in this world.

CHAPTER XV

THE GLORIOUS COMPANY OF SCIENTISTS.

The temple of fame has few more glorious seats than those adorned by the pioneers of science. Inspired by a pure love of science, and untainted by ulterior motives, they dedicated their lives to the cause of scientific advancement. Receiving scant encouragement from the world, and struggling through heavy odds, these gallant souls pressed ever on to the realm of truth and light. The firm resolution with which they faced thorny problems, and ventured into perilious fields of research, fills our minds with admiration. Without deploring their shortcomings, they took the best advantage of their opportunities, and make good use of their talents in the service of science.

The beautiful examples of selfless devotion set by those eminent men of science have gone down from generation to generation, inspiring young men and women to follow in their footsteps. Myriads have responded to the appeal; and the army of research workers swells from day to day. Waving aloft the banner of truth they march forward from victory to victory. The forces of darkness flee at their approach; and the frontiers of the realm of scientific knowledge expand before them.

Nature still presents many mysterious phenomena to be solved. There are yet multitudes of disconnected facts to be harmonized. Science

welcomes with open hands all those who are willing to serve her. Her sons who are already in the field stimulate young hearts to activity and endeavour. He who wishes to join the happy band may offer his telents however humble at the altar of science, in the confident expectation that she will inflame his flickering spark into a brilliant blaze.

One who is untutored in the methods of discovery and invention may stand appalled before a wonder of modern science like the radio. In the same way, a young student introduced for the first time to the marvels of physical science may wonder how the scientists were able to weave such a lucid theory as that of atoms and molecules, without ever seeing them. When, however, the various steps leading to the latest model of the instrument, or the complete theory, and the vast number of investigators who contributed in some way or other to their perfection, are understood, the atmosphere of mysterious wonder will be dispelled; and one will find in oneself much in common with the great men of science, and feel confident to follow in their footsteps.

If the great Faraday were to visit to-day a modern power house, and witness the battery of dynamos whirling merrily, he would hardly recognize his own child in those superb examples of modern engineering skill. Discoveries and invention do not spring forth full-grown and clothed like the goddess Maha Lakshmi from the ocean of milk. They begin in a small way and

grow stage by stage. They are fruits of the labours of countless workers, each contributing his mite in his own characteristic way. Perhaps you too may be able to pick up a small stone, and lodge it in position on the rising walls of the magnificent edifice of scientific knowledge.

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