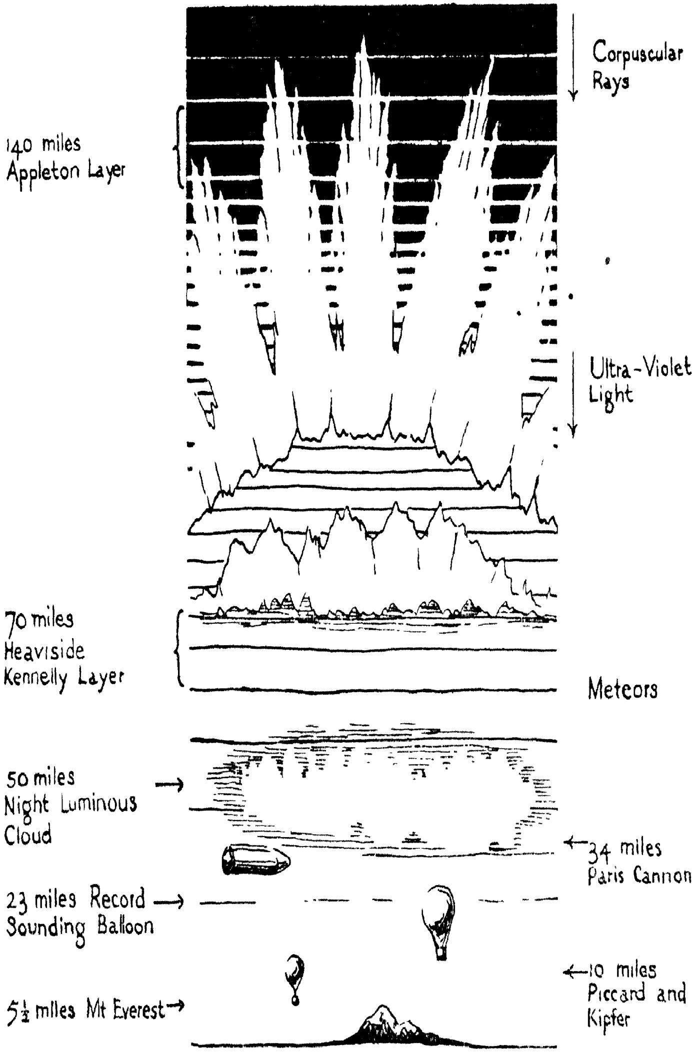
EXPLORING THE UPPER ATMOSPHERE



EXPLORING
THE UPPER ATMOSPHERE

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Introduction

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Books, whose appeal is directed mainly to the wide circle of readers interested in following the general progress of scientific research, are usually prefaced by an introduction which is essentially simpler than the text. In the present case it has been found expedient to reverse this practice. It is hoped that the preliminary slightly steeper climb will serve to make the rambles in the higher regions with the author easier and pleasanter. But those who, for one reason or another, are not desirous of the exertion required by the initial ascent, may skip the introduction altogether, and start straight away with the text, in which the slopes are so gently gradated that the height thereby gained comes as a gratifying surprise.

By a strange coincidence the periods of greatest advance in modern physical science have coincided with the turning-points of the last two centuries. It was in 1803 that Dalton laid the foundations of the atomic theory for physics and chemistry, and it was in the last decade of the same century that Röntgen, in 1895, made his discovery of the existence of X-rays, which was followed early in the next year by Becquerel's discovery of the radio-activity of uranium compounds. Planck's classical researches on the theory of radiation which culminated in the enunciation of the now famous quantum theory, were published in papers that appeared between 1897 and 1901. They were followed in 1905 by Einstein's fundamental photo-electric equation and his Special Theory of Relativity.

The Röntgen rays, and the various rays (alpha-, beta-, gamma-) emitted by radio-active elements, provided scientists with powerful miniature searchlights which could be directed into the very heart of the atom, and which ultimately succeeded in exposing its workings and its structure. However extravagant the hopes that were raised in the minds of scientists may have appeared at the time, they were far surpassed by the results which were subsequently achieved.

Before 1895 it had been found possible to explain most of the properties of matter known at that time by conceiving the atom to resemble a very minute, perfectly elastic sphere—a kind of miniature billiard-ball. This atomic model was applied with great success, for example, to explaining the physical behaviour of gases. Electricity was regarded, in general, either as a mysterious agency which could act 'at a distance', or as a unique fluid devoid of atomic structure.

The earliest known record of a phenomenon connected with the discharge of electricity through gases dates back to 1667, and refers to the fact that the Florentine Academicians had observed the loss of charge from electrified bodies when flames were brought into their neighbourhood. Only five years later Otto von Guericke discovered the electric spark, but no suggestion was made that free elementary electron charges existed. Nearly two centuries then elapsed before Plücker, in 1859, observed that when a discharge passed through a tube containing air at a low pressure, a fluorescence manifested itself at the end opposite the negative electrode of the tube; he ascribed this effect to a current which passed from the cathode to the glass walls of the tube. A suspicion gradually arose in the minds of physicists that certain hitherto unknown rays were being produced in the tube and that their nature was different from that of the already familiar heat and light rays.

In a lecture given to the British Association in 1879, Crookes dealt with the 'fourth, or radiant state of matter' that had been occupying the attention of Hittorf, Goldstein, and other contemporaries. By 1896 the idea that an elementary negative charge existed had become fairly well established, thanks to the researches of Wiechert, Kaufmann, and J. J. Thomson. The name 'electron' had first been used by Stoney in 1891 to denote these elementary negative charges. In the same year that the Röntgen (or X-) rays had been discovered, Perrin proved experimentally beyond doubt that negative electricity was transported by the cathode rays in the discharge-tubes.

The first measurement of the charge carried by the elementary electron was made by J. S. Townsend, who, having freshly arrived in Cambridge from Dublin, was well acquainted with Stokes's formula for determining the size of falling drops from their rate of fall through a given medium, such as air. Townsend applied this formula, which was at that time little known, to measuring the number of droplets contained in a cloud which had condensed on the ions of an ionized gas; by dividing the total charge carried by the cloud by this number he obtained a first estimate of the charge on the electron. This method was modified by J. J. Thomson and H. A. Wilson; a very accurate determination was ultimately made by Millikan.

Since it had been proved that electrons existed in the atom, and since the normal atom is electrically neutral, it was clear that corresponding positive charges must also exist in the atom. Their actual presence was not demonstrated experimentally until 1919, when Rutherford published his first great results on the artificial disintegration of the atom by means of fast alpha-particles from Radium-C. His experiments showed that with these miniature bullets, whose speed was more than 10,000 miles per second, he could eject from the very interior (or nucleus) of the atom positively charged particles bearing the same amount of charge as the electron, but of opposite sign. He also identified the particle with the nucleus of hydrogen, and showed that its mass was 1,847 times greater than that of the electron. To indicate that this positive particle was, like the electron, an elementary 'brick' in the structure of matter, he called it a proton.

It is interesting to note that an atom which resembles in some ways the later model of Rutherford and Bohr was suggested as long ago as 1846 by W. Weber. In one of his posthumous papers we read: 'Every ponderable molecule contains equal quantities of positive and negative electricity, whose masses are, however, different. It is not necessary that only one positive and one negative atom should form a molecule; this is so only in the case of hydrogen. In other molecules there are *n* positive and *n* negative electrical particles, and *n* is the atomic weight; for example, in the case of carbon it is 12, so that 1 carbon (molecule) is equivalent to 12 positive and 12 negative atoms (of electricity). The ponderable molecules may also capture electrical satellites, and so become converted into other molecules. But this view leads to the postulate that all elements have integral atomic weights. The orbits of the satellites around the nucleus and also the velocities with which they move in their orbits may be different; the different degrees of chemical action are a result of this difference.' Almost every sentence of this quotation rings true in the light of later developments.

Owing to the fact that electrons reside on the outside of atoms and protons only in the interior, the electron had been discovered much earlier than the proton, and it was originally suggested that the electrons were embedded in a kind of cloud of positive electricity. A great advance was made in 1913 when Rutherford proposed his nuclear atom, in which the positive charge was supposed concentrated in the middle of the atom while the electrons moved at great speeds round this central nucleus. With this model he succeeded in overcoming some of the difficulties of the older model, and was able to explain certain large deflections of fast alpha-particles, from radio-active sources, when they collided with atoms. These deflections could not be caused by a positive cloud charge, but could occur if a particle approached sufficiently near a highly concentrated positive charge.

An almost immediate advance was made by Bohr, who, by applying Planck's quantum idea of radiation to the Rutherford model, succeeded in establishing a link with spectroscopy. By imposing certain conditions on the nuclear model Bohr was able to account for the emission and absorption of definite characteristic colours, or spectral lines, by the various atoms. A period of unrivalled activity in the field of spectroscopy set in after Bohr and Sommerfeld had shown the way to the interpretation of the sequences of spectral lines contained in the radiation from atoms. Nevertheless, although the presence of certain lines (emission or absorption) in the spectra of stars was known to indicate the presence of certain elements in them, these researches did not contribute in any very great measure to the unravelling of the stellar spectra.

It was Saha who gave the great impetus to the science of astrophysics. He applied the principles of thermodynamics to an atmosphere of charged and uncharged particles, and showed that, even when the lines of a particular element were absent, the atoms of this element might yet be present in a somewhat 'stripped' form. More than this, he showed how it was possible to determine the density and temperature in the outside luminous envelope of stars. They could now be classified as giants or dwarfs, as of various shades of red, yellow, blue, or white, according to the spectra they emitted; definite theories of stellar evolution could be formulated. In a few years astrophysics, like relativity, has grown into a vast subject in which, with increasing knowledge, an increasing number of problems have presented themselves.

But there are other branches of physics, which, thanks largely to the suggestiveness and fruitfulness of the Rutherford-Bohr atom, have also passed through a phase of rapid development in recent years. We need refer only to geophysics, including seismic physics, and meteorological physics, where we can make our observations directly, and are not dependent on the messengers of light alone, as in the case of astrophysics.

There is one field of physics, however, which is delimited in a somewhat peculiar way, inasmuch as it is accessible to direct experimentation, by means of balloons, both manned and unmanned; to indirect experimentation, by studying the transmitted solar radiation in its various forms; and to semi-direct experimentation, by investigating the reflection of sound and radio waves. This branch of physics may well be called *stratospheric physics*, as it deals with the physical conditions in the upper layers of the earth's atmosphere. (In this case we use the term stratosphere to denote the whole of the shell of atmosphere outside the lower troposphere.)

It had formerly been imagined that the upper regions of the atmosphere, beyond the zone in which our ordinary meteorological conditions are of importance to human affairs, presented few or no features of interest to the scientist. It was supposed that in this region both density and temperature gradually became less, until the atmosphere merged into interplanetary space. It is only in the last few years that it has come to be realized that the stratosphere, in spite of its apparent serenity, is a turbulent zone rich in physical features of a unique kind, and of a structure far more complicated than the somewhat blustering lower regions.

The courageous first ascent into the stratosphere by Professor Piccard and Dr. Kipfer has called attention to the potentialities of this region, but whilst Professor Piccard's investigations have become a matter of popular knowledge, other investigations less adventurous, but no less interesting, have not yet become as generally known. It is from experiments and observations which initially appear to have little in common that an insight into the structure and composition of the stratosphere has been gained.

There is no need to enumerate these different types of experiment, for they have been assembled in the present book, and are described in chapters under their several headings. The author has dealt with each type of experiment as if it were a voyage of exploration, and, beginning with the regions near to the earth, has explained the nature of the voyage, and stated the knowledge gained as its result. In this way she takes us, stage by stage, into the uppermost reaches of the atmosphere, and even trespasses for a while in interstellar space.

We cannot complain that the journey is a dull one. The author's belief appears to be that the dullest fact cannot remain dull if its significance has once been understood; for her Science advances in the company of Romance and Poetry, and they are all three equally dependent on one another. But however unorthodox her manner, her facts are carefully accurate, and her matter will bear the most orthodox scrutiny.

It will become evident in the successive chapters, in which various atomic or molecular properties are called into action according to the problem under consideration, that it is our nuclear atom with its electronic satellites that has been the interpreter of the observed phenomena, and for this reason a short history of the atom appears an appropriate introduction. Without this model little progress would have been possible.

From the point of view of the scientist, and in particular of the physicist, the universe is a vast collection of laboratories in which experiments are being conducted with unceasing activity and in endless variety. No matter whether we regard the stars as furnaces from which secrets may be wrested from atoms in the most extreme state of agitation, or whether we take as our laboratory the less violently agitated stratosphere of our own earth, it is the atom and its properties which are the subject of investigation, and which ultimately give the clue to the infinitely varied phenomena that come within our powers of observation. For that reason no investigation of the upper reaches of the air is intelligible without some knowledge of the structure of the atom, and this alone makes it possible for us to correlate all observed physical phenomena.

When the atom had been resolved into its ultimate constituents it was believed that it was for the most part empty of matter. The more recent view, however, is that the elementary particles are not concentrated at points, but are disposed in the form of a charge-cloud. Similarly the stratosphere, which once appeared almost devoid of content, discloses an ever increasing complexity of structure.

Weyl has stated that 'it is the essence of a real thing to be inexhaustible in content.' This remark applies most aptly to Einstein's space, whether it refers to the stratosphere or to the extremes of interstellar space and intra-atomic regions. From the network of space, as recorded in our measurements, there emerge the physical phenomena that are received by our senses and are interpreted by our minds.

Much will yet be discovered, and new problems will present themselves unceasingly, disclosing the infinite richness and variety of our nearer surroundings as well as of those that will for ever remain beyond our reach. It is the purpose of this book to give a survey of the present state of our knowledge of the stratosphere, in such a way that it can be understood without the necessity for consulting other books of reference. For the scientist it forms a convenient anthology of the latest research in this particular region; for the unscientific it is an introduction to scientific facts well calculated to arouse the desire for further acquaintance with a subject whose attractiveness is at last becoming generally recognized.

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October, 1933.

Chapter One

Ballooning in Adventure and in Research

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Until Professor Piccard's ascent in May of the year 1931 the mention of ballooning was apt, in circles not specifically scientific, to provoke a smile. We were inclined to think of the balloon as something rather useless and a little ridiculous; we connected it perhaps with the plump balloon-seller outside Kensington Gardens who was such an attraction to the 'Boy Who Would Not Grow Up', or with the balloon ascent at the Crystal Palace in 1851 which inspired such awe in the breasts of our grandmothers. We spoke of the balloon in the same breath with the Albert Memorial and cricketers in top hats, and marvelled that the dear Victorians could have been entertained by such childish things.

It was Professor Piccard who rescued the reputation of the balloon from its somewhat ignominious position in popular esteem, and earned for it the respect already accorded to the aeroplane, the speed-boat, and the racing car. A closer acquaintance with the history of ballooning, however, reveals the fact that this respect was long overdue, and that from the point of view both of heroic adventure and scientific utility it should have been accorded from the very beginning.

From the historical point of view ballooning may be said to have begun with Leonardo da Vinci, who dreamed of flying, and towards the end of the fifteenth century succeeded in inventing a kind of parachute. In the seventeenth century Simon de la Loubère writes of a Siamese who was in the habit of climbing into tall trees and, with two open umbrellas fastened to his girdle, descending gently through the air to the ground. The umbrellas of the period must have been considerably larger than those designed for the protection of the slim ladies of to-day, and their curves also must have followed a bygone fashion and have been more ample.

The balloon proper was invented by two brothers, Joseph Michael and Jacques Etienne de Montgolfier, who made experiments with paper bags filled with smoke, and in 1783 sent up a paper-lined linen balloon at Annonay, in France, viewed by an astonished crowd, who wondered, as we still do in other circumstances, what the world was coming to next. The first ascent of a manned balloon was made in the same year by Pilâtre de Rozier and the Marquis d'Arlandes, in a balloon of a similar type, beneath which was suspended a basket structure for passengers. In order to provide a continuous supply of smoke for its lifting power, a fire-basket was fastened beneath the balloon, and the airmen furnished themselves with bundles of wood with which to replenish it. They also carried wet sponges to extinguish the flames when the gear caught fire; and, whilst one was occupied in heaping on fuel to prevent the balloon from dropping into the Seine, the other was busy putting out the flames on the burning fabric. In spite of these difficulties and dangers they succeeded in crossing over Paris, and returned to earth, the first aerial passengers since Daedalus to alight in safety.

The history of the smoke-balloon, however, is short, for in 1766 hydrogen had been discovered by Henry Cavendish, and at the time of de Rozier's ascent experiments were already being made with a view to testing its lifting power. Shortly afterwards a Frenchman in a balloon filled with hydrogen reached a height of 1400 feet, weathered a thunderstorm, and accomplished in safety a journey of 30 miles.

Ascent now followed ascent in rapid succession, and ballooning was promoted from the order of the fantastic to that of the practical. Scientists were quick to see and utilize its possibilities for the purpose of research, and in 1804 a French physicist (again a Frenchman! Is the buoyant nature of the Latin temperament responsible?), Gay-Lussac, ascended to a height of nearly 4½ miles, with the object of making observations on magnetism.

For sheer courage and endurance no recorded flight has surpassed the performance of the scientist Glaisher and his fellow balloonist Coxwell, who in 1862 reached a height of about 7 miles, in spite of the fact that at that time the use of oxygen in regions of low pressure had not been heard of. When the balloonists decided to return to earth they found that the valve-rope, which should control the expulsion of gas and so start the balloon on its downward course, had become entangled in the leading lines, and would not work. The temperature was below zero (Fahrenheit), and as Coxwell climbed into the rigging to disentangle the rope his hands became frost-bitten. Meanwhile the balloon continued to ascend into regions of lower and lower pressure; breathing became difficult, almost impossible. Glaisher lost the use of his limbs, and fell back into the car of the balloon unconscious. At last Coxwell succeeded in disentangling the rope, only to find that his hands had become utterly useless. Summoning all the energy remaining to him, with a last desperate effort he tugged at it with his teeth, the valve opened, and the balloon descended into safety.

After the introduction of oxygen for breathing purposes the attainment of great height was attended with far less risk, and balloons became a recognized and valuable means of exploring the Upper Atmosphere. Records were made only to be broken. Until Professor Piccard's ascent the height record was held by an American, Captain Gray, who attained a height of 8.5 miles, so beating his own previous record of 8.09 miles; this last adventure, however, cost him his life. In touching on the tragedies of ballooning it is perhaps not altogether out of place to mention that of Salomon Auguste Andrée, who set out in 1897 to cross the North polar region from Spitzbergen to Alaska, and was not heard of again until August 6th, 1930, when his frozen body was recovered by an expedition under the leadership of Dr. Gunnar Horn, who brought back to Sweden his recording instruments and diaries, which revealed the heroic story of three days' ballooning, three months of struggle with the ice; then thirty-three years of silence.

Before giving any account of Professor Piccard's flight a short explanation of the general structure of the modern balloon may be helpful in appreciating the difficulties which he encountered. The balloon of to-day is filled either with hydrogen or with coal gas. The weight of coal gas is 37½ pounds per 1000 cubic feet, that of hydrogen 5 pounds per 1000 cubic feet, figures which make quite evident the advantage of the latter over the former in lifting power. The weight of the atmosphere at sea-level is approximately 75 pounds per 1000 cubic feet, so 200 pounds of hydrogen—that is to say 40,000 cubic feet—would displace 3000 pounds of air—also 40,000 cubic feet. Allowing 600 pounds for the weight of balloon and gear, there remains a lifting power of 2000 pounds for passengers, instruments and ballast.

In practice the weight is so adjusted by means of ballast that a balloon generally rises from the ground with a lifting power of from between 20 and 100 pounds, although this practice was not observed in the case of Professor Piccard, who, in order to attain greater height, left the ground with considerably more than the normal lifting power.

Just as water, being heavier than air, falls, so hydrogen, being lighter than air, rises, and it is as necessary to fill a balloon from below as it is to fill a bucket from above. The bottom, or neck of the balloon, is left open during an ascent so that, as the balloon rises into regions of lower pressure, the expanding gas, instead of bursting the envelope as it would otherwise do, can escape through the open neck. As the pressure decreases the weight of the air per cubic foot becomes less, approximating gradually to the weight of hydrogen. When the balloon reaches a point at which the weight of the air it displaces is exactly equal to that of the hydrogen it carries, minus the weight of the quantity that has been lost, and plus the weight of balloon, gear, passengers, etc., its progress should stop, and it should remain in equilibrium, neither ascending nor descending. It has, however, gathered momentum on its upward journey which carries it past the point of equilibrium, whilst the gas still continues to expand and escape; and when the balloon eventually comes to a standstill the weight of air displaced is less than that of the balloon and gear, and it must consequently begin to descend. To check its descent ballast is thrown out; but, although during its descent no gas is lost owing to the fact that it is falling into regions of higher pressure, the balloon again gathers momentum that carries it beyond its second point of equilibrium, and directly it comes to a halt it begins to go up for the second time. On the second upward run no gas is lost until it reaches the height attained on its first ascent; at this point the expanding gas must again overflow until the balloon reaches and overshoots its new altitude of equilibrium, this being determined by the weight of ballast discharged, minus the weight of gas lost, allowing, as always, for the momentum it has gathered. In this way a balloon journey is made in a series of ascents and descents, each ascent being higher than the last. Unless something unusual occurs a balloon will continue to rise until it has lost a sufficient quantity of gas to bring it to a standstill, and will continue to fall until sufficient ballast has been discharged to check its downward course.

When a landing has been decided upon the usual method used to effect a descent is that of pulling the valve-cord, which allows the gas to escape gradually from the balloon envelope. When the balloon is close to the earth the rip-rope, which detaches a panel in the side of the envelope, may also be pulled, but it must not be used when the balloon is at any considerable height, for the gas then escapes with great rapidity, and an abrupt fall is the consequence.

In addition to pressure, temperature has an important effect on the behaviour of a balloon, for when the gas with which it is filled becomes warm it expands, and in increasing the displacement of air increases proportionately its lifting power. Similarly when the gas is cooled the displacement is decreased, and the lifting power reduced.

When a balloon makes an ascent on a sunny day, it must first rise through the mist which lies close to the earth's surface and has the effect of making the sky appear a silvery blue. As the balloon ascends the mist becomes more tenuous, the blue of the sky grows darker, until, beyond the mist that is present though not apparent below, it attains a rich violet colour, ten times darker than it appears when seen from the earth, but yet not quite dark enough to allow the stars to become visible.

Piccard's balloon is named 'F.N.R.S.', the initials of a Belgian organization, *Fonds National de Recherches Scientifiques*, which exists for the purpose of assisting scientific enterprise, and which financed the ascent. The envelope has a cubic capacity of 14,000 cubic metres, almost three times the cubic capacity of Andrée's balloon, and a little less than twice the cubic capacity of the 'Preussen', one of the largest balloons previously constructed. It was filled to only a little over one-fifth of its total capacity, so that the gas might have room to expand without escaping, and so bring it to equilibrium at a height of about 8½ miles, the discharge of ballast allowing for a further ascent of between 1 and 2 miles.

The cabin, more familiarly known as the gondola, is constructed for lightness' sake of aluminium, and is not unlike a diver's helmet in appearance, for it is a round ball about a man's height in diameter, and contains two small man-holes, and eight small circular windows, or 'bull's-eyes', through which the two occupants are able to obtain a view both above and below.

Just before dawn on May 27th, 1931, August Piccard and his engineer Paul Kipfer entered this little ball-shaped structure. They wore curiously shaped helmets of basket work, ridiculous enough in appearance, but which no doubt saved their skulls when the balloon eventually came to earth with such precipitation. They had with them their instruments, a supply of oxygen, and a quantity of lead ballast. In the excitement of preparation their flask of mineral water was forgotten, and when, in the stifling interior of the constricted cabin, they were assailed by thirst, they were glad to drink the moisture that became condensed on the walls.

Immediately they were inside, the man-holes were sealed up and the balloon released. It shot up into the air as if it had been discharged from a gun. As the astonished onlookers watched it rise it looked like a gargantuan yellow pear lit up by the rays of the rising sun; whilst they watched the pear gradually changed its shape as the gas expanded and filled the envelope, until it was no longer a pear but an amber ball, which continued to ascend until the ball became a daytime star, and at last no more than a pinpoint of light. In 25 minutes it had reached a height of over 8 miles, travelling at an average speed of approximately 20 miles per hour, whilst the velocity with which it started its ascent must of course have been considerably greater.

Although the balloon was released at two minutes to four it was not until nearly an hour later that Piccard found leisure to enter up his log. The sudden jerk as the balloon left the ground had done considerable damage. The broken oxygen apparatus must be repaired without delay; the thin wall of the cabin had been dented in such a way that the aperture into which an electrostatic recording instrument should have been inserted was not completely closed. No sooner had this been rectified than an ominous whistling sound betrayed the fact that another leak had occurred elsewhere. It was essential that all contact with the low pressure of the atmosphere outside the cabin should be cut off immediately, and whilst Piccard occupied himself in mending the leak with oakum and vaseline Kipfer watched the barometer.

In 28 minutes the balloon reached its first point of equilibrium. The barometer registered a pressure of 3.2 inches (as compared with 30 inches at the earth's surface) indicating a height of over 9½ miles. Inside the cabin it appeared to be snowing, for the increasing heat of the sun detached the hoar-frost that had collected on the roof and it came showering down upon the occupants.

The repairs accomplished, Piccard believed that all was well, and just before six he decided on a further ascent. Ballast was cautiously discharged and the balloon rose into a region of pressure of 3.1 inches, indicating a further gain in height of one-fifth of a mile. As the sun rose higher the cabin became bright and warm, the hoar-frost melted and trickled down the walls in little streams.

At about half-past six the disquieting discovery was made that the valve-rope was entangled amongst the thirty-two leading lines that attached the cabin to the balloon. As the envelope was still expanding under the influence of the heat of the sun, and so altering the position of the leading lines, it might be pulled automatically and so cause a too rapid descent. In spite of this new anxiety, however, and in spite of his suspicions of the existence of a second leak Piccard found leisure to comment in his log on the beauty of the scenery below, and on the beautiful dark-blue colour of the sky above.

He decided on a further ascent, and again ballast was discharged. The heat of the sun became greater still, for they were far above earth-mists now, and it had not yet reached its zenith. One side of the cabin—the other was protected by the shadow of the balloon—became almost unbearably hot. Delicate clusters of ice crystals were observed round about the balloon, a phenomenon that has not yet been explained.

After a voyage of about 6 hours, approximately the time he had intended to remain aloft, Piccard decided to pull the valve-rope and so to begin a gradual descent. But before he could pull it he must disentangle it from the leading lines with which it had become involved, and whilst he was attempting to do so the rope broke. The balloonists watched the frayed end dangling far out of reach and utterly useless. Buoyed up in the stratosphere by the increasing heat of the sun Piccard and Kipfer, like Glaisher and Coxwell before them, were prisoners of the air.

With careful use the oxygen would last until sunset, when the gas would cool and contract, and so cause the balloon to descend. For 5 hours at least there was nothing to do but wait, and take regular readings on the instruments. The heat was becoming intolerable, clothes were discarded, another leak was located and mended. Then an appalling discovery was made. In their attempts to disentangle the valve-rope a barometer had been broken, and mercury was falling drop by drop on to the aluminium floor of the cabin. Mercury eats its way rapidly through aluminium. Would the floor of the cabin collapse, or would the coat of varnish with which it was covered be sufficient to withstand the mercury?

At that moment Piccard and Kipfer realized that their lives were dependent on a thin coat of varnish. Nevertheless it proved sufficient.

Then followed long hours of waiting, during which they sat in their tiny world, the belts of their parachutes fastened to their bodies. Again and again the balloon seemed about to sink, again and again they were disappointed. The moon rose, and slowly, very slowly, the sun curved down towards the horizon. At about 8 o'clock in the evening they had sunk to a height of 7½ miles.

Once definitely started on its downward course the balloon gathered momentum on its way; the sun set, dusky red; below them they saw the snow-clad Alps, giant teeth piercing the clouds, fantastically lovely. They had attained a downward speed of one-sixteenth of a mile per minute. Ballast was discharged to steady the fall; the balloon threatened to rise again, Kipfer pulled the rip-cord, and the balloon subsided on to a glacier, down which the round cabin rolled, and came to rest at an angle of 120 degrees. They had landed safely near Ober-Gurgl, in the Innsbruck region, after a voyage of 17 hours, during which they had reached a height of 9.95 miles.

Undaunted by his experiences on his first ascent Piccard made a second ascent from

Zürich on August 18th, 1932, accompanied by the young Belgian scientist, Max Cosyns. On this occasion they reached a height of 10 miles without untoward incidents, and descended safely near Lake Garda. Owing to some extent to the experience gained on the first ascent the second was uneventful from the standpoint of adventure, but the scientific results were of more importance than on the first occasion.

During the summer of 1933 attempts were made in three different countries to beat the height record set up by Piccard and Cosyns. Cosyns himself, again financed by the *Fonds National de Recherches Scientifiques*, made preparations for an ascent from a field on the bank of the Lesse, in Belgium. He intended to make use of a stabilizing balloon in order to make possible a very gradual ascent, and so facilitate frequent scientific observations in lower as well as higher altitudes. This device was also designed with the purpose of preventing lateral drift, which has previously made it imperative that ascents should be made only at a considerable distance from the sea-coast. Unfortunately, owing to an explosion which occurred during the testing of part of the apparatus, one of his workmen was killed, his laboratory was partially wrecked, and the project had to be abandoned until the following year.

In America, Professor Jean Piccard, the brother of Professor Auguste Piccard, superintended the preparations for an ascent which was to be made by Lieutenant-Commander Settle, an American naval officer, in a balloon constructed specially for the purpose, with a capacity some 100,000 cubic feet greater than that of the 'F.N.R.S.' The ascent was made in the neighbourhood of Chicago, and it was hoped that Settle would reach a height of about 15 miles. In a successful ballooning adventure, however, size is not the only matter of importance, and on this occasion, as on that of Piccard's first ascent, the working of the valve was a determining factor. But Commander Settle's experience was the exact opposite of Professor Piccard's, for the valve of his balloon, which he had opened in order to steady the rate of ascent, refused to close again, the gas escaped rapidly from the envelope, and instead of becoming a day-long prisoner in the stratosphere, he was bumped down on to some railway lines little more than a quarter of an hour after he had left the ground. Luckily neither he nor the balloon was seriously damaged, and it is probable that his next attempt will be more in keeping with his brilliant record in the air, for he is one of the few men licensed to fly, not only a balloon, but also an aeroplane, an airship, and a glider.[1]

Russia's interest in the stratosphere came as

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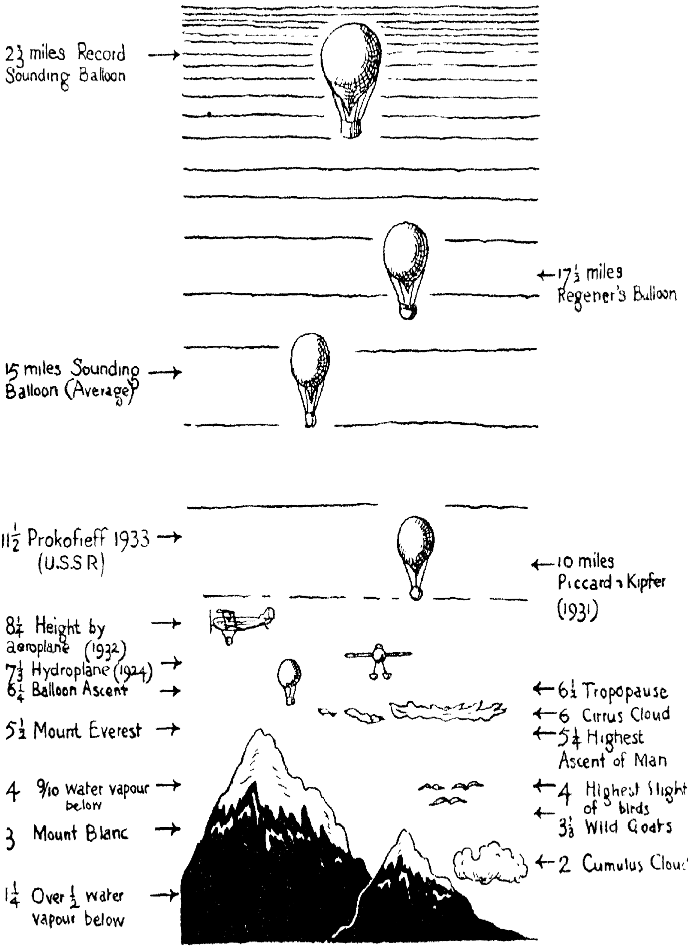
[1] On his next ascent Settle reached a height of 10½ miles.

something of a surprise to the rest of Europe, and the success of the little-advertised ascent made by MM. Prokofieff, Birnbaum, and Godunoff on the last day of September in the balloon 'Stratostat U.S.S.R.' is a tribute to the thoroughness and efficiency with which it must have been prepared. The Russian balloon has a cubic capacity (25,000 cubic metres) considerably greater than that of either the Belgian or the American balloon, and it carries a wireless apparatus by means of which the balloonists are able, during their flight, to maintain communication with the earth. Another factor which contributed to the success of the undertaking was the presence of two small captive balloons, each carrying a passenger, which hovered round the huge structure during the course of preparation. These two balloonists were able to arrange and disentangle the multitudinous ropes which present such a problem as the envelope changes its shape and position during the process of inflation, and were also able to keep a look-out for possible leaks. The ascent was made from Moscow, and within 60 minutes of leaving the earth the balloon had reached a height of 10½ miles. It remained in the air for about 7 hours, attained the record height of about 11½ miles, and descended safely at Kolomna, about 50 miles south-east of its starting-point, with instruments and records intact.

For the purpose of scientific research the unmanned balloon has played at least as important a part as the manned balloon, and, quite early in the history of ballooning, exploration of the upper air was made by means of anemometers hoisted aloft by tethered balloons or kites. In this way records were kept of wind-velocity at various known heights.

Pilot balloons have also been employed for a similar purpose. These are small rubber balloons filled with hydrogen, which are liberated and allowed to drift with the wind whilst their course is observed through the telescope of one, or preferably two theodolites. When two theodolites separated by a considerable base-line are used, observations give the position and course of the balloon, and also the velocity of its flight.

The advent of the registering balloon, which is capable of rising to a much greater height than the pilot balloon, again extended the possibilities of gaining knowledge of conditions in the upper air. The registering balloon, which, since it is used for 'sounding the heights, as the depths are sounded', is frequently referred to as a 'sounding balloon', generally carries a Dines meteorograph, which consists of a small aneroid barometer and a bimetallic thermometer enclosed together in a metal case for protection from the heat of the sun. The records, which can be read with the help



INVADERS OF THE AIR

of a microscope, are scratched on a strip of copper, and the whole apparatus, which weighs about 2 ounces, is trailed on a thread about 100 feet long, so that the air with which the instruments are in contact is not affected by heat radiated by the balloon. When the envelope bursts owing to the expansion of gas, or when the balloon descends on account of leakage, the instrument is borne gently down to earth by means of a parachute.

Quite recently Regener of Stuttgart has improved on this type of registering balloon by making a double balloon of which the outer, sealed and partially inflated, provides the lifting power. As the cubic capacity allowed for expansion is known, and also the extent of the elasticity of the fabric, this outer balloon is likely to burst at a calculable height, and the inner balloon, to which the instruments are attached, acts as a parachute and floats down with its record.

Although the idea had been suggested some ninety years earlier, it was not until about 1893 that systematic records of conditions in the Upper Atmosphere were actually kept. The pilot balloon made possible regular readings up to a height of about 2 miles, and in favourable circumstances up to a height of 6 miles, whilst occasional readings were recorded at about 16 miles. Registering balloons carried investigations considerably further; they record frequent readings up to a height of 12 miles, occasional readings up to a height of 20½ miles, and there is an isolated instance of a registering balloon sent up from Padua that is said to have reached a height of $23\frac{1}{5}$ miles. As the greatest height yet attained by a manned balloon is less than half this distance it would seem that the future of the exploration of the Upper Atmosphere lies with the unmanned rather than with the manned balloon.

Bruno Rolf, of Sweden, has published an interesting account of the adventures of these 'ballons sondes', one hundred and fifty-six of which were launched from Abisko in the years between 1921 and 1929. Each balloon bore a label on which was written an offer of a reward of ten Swedish crowns for its return to the laboratory, and in spite of the sparseness of the population of that part of Sweden—Abisko lies in latitude 68° N.—sixty-one balloons were returned to him. Enquiries were made as to the circumstances in which the balloons were picked up and these elicited forty replies. Nine of the balloons had been seen descending, and so were easily recovered; twenty-four had been returned within fifteen days; thirty-six within ten weeks; forty-eight within six months, sixty within a year, whilst one had not been returned until four years and seven months after the date of its ascent. The horizontal distances travelled varied between 1¼ and 360 miles, and the average distance was about 53 miles. In only one instance in the case of the balloons returned was the Dines meteorograph unreadable.

Chapter Two

Through the Troposphere to the Lower Stratosphere

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Since Piccard's first balloon ascent we have come to associate scientific exploration of this kind with a region, about which most of us are a little vague, known as the Stratosphere. Piccard himself has suggested that possibly before many years have elapsed the voyage between England and America will be made through this region, and gives us to understand that the journey will be both speedy and placid, accomplished in flawless sunshine, and remote from the storms and tempests that prevail nearer to the earth. No wonder that the very word Stratosphere has a pleasant sound! But what is it exactly? and where is it?

Not so many years ago, certainly not as much as half a century, the general belief about the atmosphere was that it extended for six or seven miles above the earth's surface, and then to all intents and purposes faded away into empty space. Yet above this layer of atmosphere lies the Stratosphere, and it has been suffering what almost amounts to an epidemic of balloon invasion. If it consisted of empty space only it would hardly be likely to attract scientists to so many perilous adventures.

It is easier to understand a structure if something is known of its foundations, and before embarking on an account of the Stratosphere it will be as well to call to mind a few facts about the lower atmosphere.

With regard to knowledge of its chemical composition little has actually been gained by means of balloon investigation, but a great deal by means of research in the laboratory. In 1804 Gay-Lussac collected samples of air at comparatively low altitudes, but these and subsequent similar experiments only demonstrated that the relative proportion of the different gases which compose dry air, that is to say atmosphere from which the water-vapour content has been excluded, remained much the same at these altitudes, and that it was only the pressure or density that decreased.

It has long been known that at the earth's surface dry air consists mainly of four parts of nitrogen to one part of oxygen, with the addition of a small quantity of carbon dioxide, but modern chemical methods have revealed the presence of very small quantities of several other gases.

In 1875 Lord Rayleigh, whilst making a series of experiments to test the density of nitrogen, found that specimens of nitrogen prepared from the air were invariably of a slightly higher density than that of those prepared by chemical methods. These results suggested the presence in these specimens of something other than nitrogen, and eventually he succeeded in isolating a new gas which was called argon. It is a little surprising that argon, which forms almost 1 per cent of the air at the earth's surface, should have been discovered so late in the history of chemical science. The explanation is to be found in the fact that it is one of a series of inert, or noble gases, which cannot be detected chemically because they cannot be made to combine with any other gas. These gases, in the order of their atomic weights, are: helium, neon, argon, krypton, xenon, and radon.

The existence in the air of other gases was subsequently established, and dry air may be said to consist, on the average, of the gases named in Table I in the proportions given.

TABLE I

CONSTITUTION BY VOLUME OF THE ATMOSPHERE AT THE EARTH'S SURFACE

NITROGEN	78.03	in	100
OXYGEN	20.99	,,	100
ARGON	0.94	,,	100
HYDROGEN	about 1	in	10,000 estimated

NEON	about	1	in	80,000	(estimated)
HELIUM	,,	1	,,	250,000	,,
KRYPTON	,,	1	,,	2,000,000	,,
XENON	,,	1	,,	17,000,000	,,

Traces of CARBON DIOXIDE and AMMONIA are also present in the atmosphere in varying quantities.

At the surface of the earth 1.2 per cent of the total number of molecules present in the atmosphere is provided by water vapour. To an Englishman this percentage will not be in agreement with his general impression, but he must remember that science is international, and the figure given is an average for the whole of the earth's surface, and must therefore include the atmosphere above the Sahara as well as that above Lancashire.

This percentage of water vapour decreases rapidly with altitude, a fact of which the same Englishman will become pleasantly aware if he sets out from Manchester to Switzerland and climbs the Alps. It is this dryness of atmosphere that makes the high valleys of Switzerland so favourable a locality for sanatoria for the treatment of lung trouble, for dry air means a sunny climate and the absence of mists.

Above the height of 7 miles the percentage of water vapour in the atmosphere is only 0.01.[1]

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[1] Mother-of-Pearl clouds, and the silver-blue Night-luminous clouds, which float at a height of about 16 and 50 miles respectively,

All other clouds are left behind at this height, and, although the mountaineer has a similar experience, the balloonist at any rate is fortunate enough to be able to rise into this region of perpetual sunshine. Owing to its very rapid decrease in quantity the total amount of water vapour present in the earth's atmosphere is actually less than that of argon, which is present in larger quantities at much higher altitudes.

There was at one time a theory that above the height of 10 miles, where the temperature becomes more or less constant, the various gases of which the atmosphere is composed distribute themselves according to molecular weight; and that the proportion of the heavier gases, such as nitrogen and oxygen, decreases with distance from the earth, whilst that of the lighter gases, such as hydrogen and helium, increases. It seems probable that the quantity of helium does increase considerably above a height of about 19 miles, but equally probable, in the light of modern research, that at this altitude the quantity of carbon dioxide is scarcely appreciable, and that above a height of 60 miles hydrogen, also a comparatively light gas, does not exist at all. Direct experimental observations are lacking above a height of about 20

are not taken into consideration here, for the appearance of both is somewhat rare. The latter are probably composed of very fine dust, but neither phenomenon has been finally explained.

miles, but modern spectral-photographic methods have disclosed other facts equally upsetting to this theory, and although the old barometric formula for the decrease of pressure with height is given in Table II, together with the percentage distribution of gases according to this formula, it must be remembered that it certainly ceases to be applicable in the higher regions of the atmosphere.

Strictly speaking, it is neither the subject of the chemical composition of the atmosphere nor that of atmospheric pressure which brings us to the threshold of the Stratosphere. These have their place in the orderly ascent which we are making from the earth's surface to the outermost fringe of the Upper Atmosphere, but it is the question of temperature that concerns the Stratosphere itself.

It was in 1898 at Trappes, near Paris, that Tessereinc de Bort began to compile an extensive record of temperatures registered in the upper air by means of sounding balloons. A long series of experiments showed that as altitude increased there was a uniform fall in temperature at the rate of 6° Centigrade per kilometre; that is to say, an average drop in temperature of from between 40° and 60° Fahrenheit at ground-level to between — 60° and — 40° Fahrenheit at an approximate height of 7 miles. Up to this time the belief had been held that this drop in temperature continued indefinitely, but de Bort discovered, to

TABLE II

THE NUMBER OF MOLECULES PER CUBIC CENTIMETRE IN THE OUTER ATMOSPHERE (ACCORDING TO JEANS)

GAS	AT SEA-LEVEL	AT $12\frac{1}{2}$ MILES HIGH	AT 50 MILES HIGH	AT 100 MILES HIGH	AT 500 MILES HIGH
Hydrogen	100×10^{13}	80×10^{13}	4300×10^{11}	1820×10^{11}	3×10^{11}
Helium	4×10^{13}	2.6×10^{13}	73×10^{11}	13×10^{11}	10^{6}
Neon	12.5×10^{13}	1.4×10^{13}	0.3×10^{11}	$.5 \times 10^{3}$	—
Nitrogen	$780,300 \times 10^{13}$	$42,900 \times 10^{13}$	520×10^{11}	35×10^{3}	—
Oxygen	$209,900 \times 10^{13}$	7000×10^{13}	25×10^{11}	$.3 \times 10^{3}$	—
Argon	9400×10^{13}	139×10^{13}	$.04 \times 10^{11}$	10^{2}	—
Krypton	$.5 \times 10^{13}$	10^{9}	—	—	—
Xenon	0.06×10^{13}	10^{5}	—	—	—

his own astonishment and that of every other physicist, most of whom were inclined to doubt the accuracy of his readings, that at about this level the fall in temperature stopped abruptly, and it became practically constant, whilst some readings gave even a slight rise. It was a fact that was not immediately accepted, but by 1899 further readings had established it beyond all reasonable doubt.

We must think of the earth, then, as enfolded in two distinct layers of atmosphere. In the lower one, which varies in thickness from about 6 to 10 miles, the temperature decreases with distance from the earth's surface at a uniform rate. It is this layer that comprises all that we used to know of the earth's atmosphere, and it is now known as the Troposphere. In the layer above it the temperature shows no decrease, and it is this layer that is known as the Stratosphere. Tessereinc de Bort discovered no limit to it and therefore considered it boundless, but we now know that it extends to a height of about 30 miles.

The transition region between the Troposphere and the Stratosphere, in which the change is made from the one layer to the other, is generally referred to as the Tropopause. We can think of the Tropopause as an encircling buffer state, wavering frequently in outline as is generally the fate of buffer states, which divides two regions in which the temperature speaks different languages; dare we suggest a Romantic order below, Classical above?

The height of the Tropopause shows considerable variations, and is highest (about 10½ miles) above the equator, lower in higher latitudes (about 7 miles), and presumably lowest above the poles.

There is also a variation in the temperature of the Stratosphere, which is highest where the Tropopause is lowest, and lowest where the Tropopause is highest, that is to say above the equator. From day to day fluctuations occur both in the level of the Tropopause and in the temperature of the Stratosphere; and Bruno Rolf, in his observations made in the neighbourhood of Abisko, finds also an annual variation in its temperature, which is higher in summer than it is in winter. It may be noted in this connection that the temperature registered by the 'Stratostat U.S.S.R.' on September 31st at the height of about 11½ miles was —88° F.

The lowest known temperature on ground-level is that of —76° F., recorded on the Great Ice Barrier in Ross Sea, on July 6th, 1911. The lowest recorded temperature in the Stratosphere is that of —134° F., which was registered above Batavia (latitude 5.40° N.) at a height of 10 miles. If then we want to find the lowest temperature in nature we must not go to the poles. On the contrary we must take a balloon to the equator and ascend into the Stratosphere. The sunburn we shall suffer during the first few minutes of our ascent will be amply compensated by·the frostbite that will rapidly follow as we ascend in the direction of the sun; the extremes of heat and cold will indeed be so violent that we shall be very unlikely to survive the experiment, and perhaps it is best to leave research of this kind to sounding balloons.

The discovery of the even temperature of the Stratosphere has given rise to much speculation as to its cause, and probably the most plausible explanation that has been suggested is that it is due to the balance between absorption and radiation of heat. The temperature of any given portion of the atmosphere is determined largely, though not entirely, by the counterbalance of radiation: that is, by the equilibrium of the radiation that is absorbed by that portion and the radiation that is emitted. There are various sources from which radiation penetrates the atmosphere, the sun, which is the origin of short light-waves, the earth, which emits the long heat-waves known as 'dark radiation', and also the surrounding layers of atmosphere. Of this radiation some is absorbed by the atmosphere and some is transmitted, either to the earth or to the neighbouring regions of atmosphere. When that which is absorbed and that which is lost balance each other, then an even temperature must be the result.

Other considerations to be taken into account in connection with the temperature of the Stratosphere are the limit of the height of convection, and the selective absorption of radiation by the various gases of which the atmosphere is composed. There is no intention, even if it were possible, to exhaust the subject, but rather the object is to throw out a few suggestions to show which way scientific thought is moving, just as a Boy Scout wets his finger to find out which way the wind blows, a method which, if it does not give the exact point of the compass, indicates at least the general direction.

In writing of the exploration of the Upper Atmosphere by means of balloons, Bartels has declared that heights above 20 miles, just as depths below 6 miles, are as far beyond our reach as the moon and the stars. It seems that it is so, but the modern scientist, unwilling to accept so easy a defeat, has found other means, and has pressed into service the help of other explorers, better equipped than are balloonists to travel through the wide regions of space. If we are to learn anything of the regions above the Lower Stratosphere it is to these voyagers that we must turn for further information.

Chapter Three

Sound as an Explorer

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There were few things in life that did not arouse either the interest or the curiosity of Samuel Pepys Esquire, but, whilst his love of the theatre and of good dinners, of laced coats and fine women is notorious, his interest in science is apt to be overlooked. In 1664, the year in which he bought a 'periwigg' but did not wear it, he became a member of the Royal Society; in 1684 he was its president; and among the vivacious records of dull sermons and court scandals, of foreign wars and domestic economy, several accounts of scientific experiments find a place. It is to Pepys that we owe the earliest known reference to the peculiar behaviour of sound. During the Dutch War, in 1666, he relates how he saw hundreds of people assembled in St. James's Park listening to the firing of the guns of the Fleet in the English Channel, and goes on to say that this same firing was not heard at all either at Deal or Dover. He had made a previous observation of the same kind a day or two earlier and the facts set him wondering.

'This', he writes, 'makes room for a great dispute in philosophy, how we should hear it and they not, the same wind that brought it to us being the same that should bring it to them: but so it is.' Had Mr. Pepys been kept less busy at the Admiralty, or had his spare time been less occupied by 'walking with my lord' and by teaching the musical Mercer to sing, he might not have dismissed it merely as 'a miraculous thing'. As it was, nearly two centuries and a half must elapse before this idiosyncrasy of sound, which made it audible at great distances, whilst it was inaudible at lesser distances in the same direction, was further investigated.

Even as late as 1883, in the accounts of the eruption of Krakatoa no mention is made of this curious fact. Two-thirds of an island, a cubic mile of earth, was hurled into the sea; 163 villages were wiped out; 36,380 people lost their lives; clouds of volcanic dust encircled the earth; and 100 miles away the darkness was so great that day was turned into night. The sea became so hot that fishes took refuge on the inhospitable shores of the surrounding islands, so that the natives still say, 'When the fishes come ashore the Silent Mountain is about to speak.'

It is little wonder then that the Silent Mountain made itself heard over nearly one-eighth of the earth's surface. Krakatoa is situated at the east end of the Strait of Sunda, between the islands of Java and Sumatra; the explosion was audible in Southern and Western Australia, 1300 and 2250 miles away; at Bangkok, 1413 miles away; in the Philippine Islands, 1450 miles away; in Ceylon, 2058 miles away; and in Rodriguez, an island 3000 miles away in the Indian Ocean, so great a distance that it took the sound 4 hours to reach it.

Had the explosion occurred in one of the Canary Islands it would have been heard in Liverpool; had Vesuvius been capable of an eruption of as great a magnitude it would have been audible at the North pole.

The fact that the sound of this terrific eruption travelled such immense distances is interesting as well as impressive, but it would have been even more interesting had any record been made of the places within this general area of audibility at which it could not be heard. There is no doubt now that there were such districts, but at the time the subject aroused little interest. The 'dispute in philosophy' that had intrigued Pepys had been for the time forgotten.

It was a German scientist, von dem Borne, who revived it. He inferred from the facts already available that sound-waves travelled in an upward direction to a considerable height, proceeded at greatly increased speed for some distance, and then turned downwards to the earth again. In order to substantiate his theory he collected as much information as possible about the audibility of a great explosion that occurred in Westphalia in 1903. From these facts it became quite clear that sounds of this nature were heard with decreasing intensity up to a certain point; that beyond this point was a belt, which became known as the zone of silence, in which the sound was completely inaudible; and that still farther away it again became audible, until for a second time it vanished.

As sound-waves are sent out in every direction, we can imagine a ring round the site of an explosion within which the sound can be heard. This ring, in the case of a big explosion, has an average radius of about 60 miles, but owing to varying conditions of wind and irregularities in the earth's surface it can only very roughly be described as circular. Outside this area is a belt of about 125 miles in breadth in which the sound cannot be heard, and beyond this belt yet another in which it is again audible. In some cases there may even be a second zone of silence and a third zone of audibility, that is to say one area of normal and two of abnormal audibility.

During the war this phenomenon became more generally known, for it was noticed that firing on the western front was frequently heard in England, far beyond the zone of normal audibility. After the war, when it became necessary to explode dumps of ammunition, meteorologists, who by this time had become really interested, took advantage of the opportunity, and posted reliable observers at varying distances from the site of the explosions, so that more accurate data might be obtained.

The information so gathered confirmed the correctness of the observations already made, but resulted in no satisfactory solution of the problem as to why sound-waves should behave in the way postulated by von dem Borne.

At this period several long-established facts concerning the nature of sound-waves were recognized. It was known that they were longitudinal, that is to say that they travel in forward pulses, in contrast to radio-waves, for instance, which are transverse, and, if they are regarded as motions in a hypothetical ether, have a similar motion to that of a rope when it is shaken up and down at one end, in such a way as to form a series of curves along its length.

It was also known that the medium in which the compression-waves of sound travel was air, a fact worth noting by those of us who in a noise-infested atmosphere long for the refreshment of silence. In order to obtain it we must surround ourselves with a vacuum, which, odd and impracticable though it may seem, is probably our only effective defence against the incessant bombardment of din. The fact that at a given temperature ·and in a given gas sound-waves move at a uniform speed, regardless either of pressure or of the distance from their origin, was also common knowledge.

We have all watched children calculate the distance of a thunderstorm by counting the seconds that elapse between the flash of lightning and the peal of thunder, allowing 5 seconds for every mile of distance. The result may lack the precision of scientific requirements—for who can resist the temptation to hurry his seconds a little so that he may feel farther removed from the storm?—but it is based on the scientific facts that sound travels at the rate of one-fifth of a mile per second, and that the speed of light is a million times greater, and therefore can be ignored for the child's purpose.

When more accurate calculations are in question, however, two other facts must be taken into consideration, the first that the velocity of sound varies in different gases, the second that the velocity increases as the temperature through which it travels becomes higher, and decreases as it becomes lower. It is the latter fact that accounts for the course of those sound-waves that leave the earth's surface, for as they rise into regions of lower temperature they become refracted, and instead of travelling in straight lines travel in concave curves.

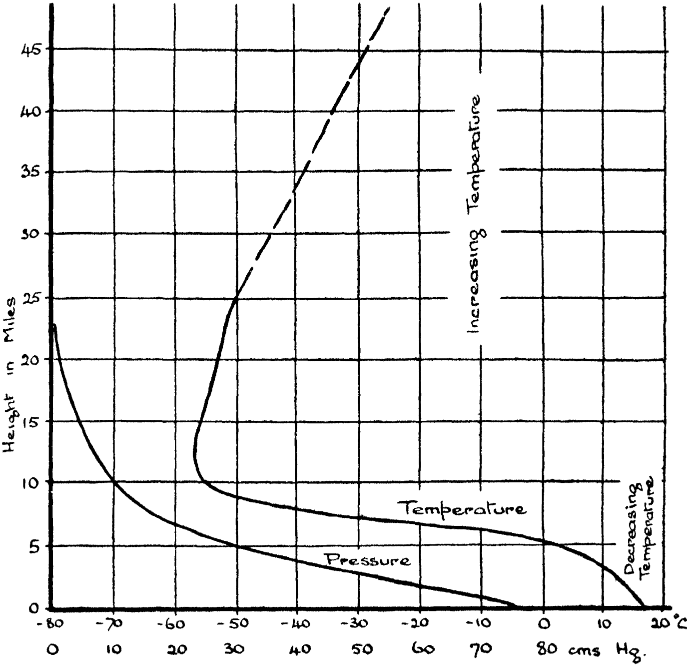
It is not impossible that a little confusion may exist in some minds between the law of refraction and that of reflection, and before proceeding further it might be as well to make the distinction perfectly clear. The law of reflection implies that light is projected from the surface which reflects it at the same angle at which it strikes it, as a ball is bounced from a hard surface. This law was already known to the ancients, but the law of refraction, which implies bending, rather than bouncing, was discovered by Snell in the reign of James the First.

We can imagine a polished rod rolled along the smooth surface of a billiard-table. As long as the surface is uniformly smooth the rod rolls in a straight line; if, however, one half of the rod encounters a surface of thick velvet pile the progress of that portion is slowed down, and consequently the other half of the rod must alter its direction. The rod no longer rolls in a straight line, but turns in the direction of the slower-moving portion; were it flexible, like light or sound waves, it would curve.

Sound-waves, then, either travel along the ground in a horizontal direction until they are completely absorbed by the molecules of the atmosphere near the earth, or rise through the troposphere in a curve that is concave downwards, until they become inaudible at the earth's surface. As long as the fall in temperature continues the curve is maintained, but when the sound-waves reach the stratosphere, where the temperature is uniform, the refraction ceases, and the waves travel onwards in their final direction in a straight line. In this region of the atmosphere the molecules of air are comparatively few and far between, and consequently the waves can travel long distances without being absorbed. It may be added that the actual direction of the wind has little to do with the distance at which sound can be heard. We are reluctant to disturb any of Pepys's comfortable beliefs, but truth compels us to state that sound in the upper regions is not as he implies, carried by the wind, although it is influenced by it. The wind that makes for audibility in, for instance, a westerly direction may come either from the east or from the west. In the case of an east wind it must increase in strength as its height above the earth increases; in the case of a west wind it must decrease with height. If these conditions are fulfilled either an east or a west wind is equally favourable for the passage of sound-waves close to the earth in a direction westwards from its source.

At the time at which experiments were being carried out in connection with the explosion of ammunition dumps (1920-1921), the general belief held by scientists was that the temperature of the stratosphere continued constant, and there seemed no reason whatever why sound-waves should not continue in their upward direction until they were lost in space. The existence of a zone or zones of abnormal audibility proved that they certainly did not do so, and the problem then arose as to what it was that obstructed their course and sent them back to earth.

One suggestion made was that they were carried down by the wind. This could only be possible if there existed a region of high wind-velocity in the stratosphere, but even in that case the sound would return to earth on one side only of its origin, and observation had made it clear that beyond the zone of silence there was a circle, often complete, of abnormal audibility. Von dem Borne's theory was that the course of sound-waves was altered by a change in the composition of the atmosphere. A high proportion of hydrogen was at that time believed to be present in the upper stratosphere, which would be sufficient if it existed to act as a reflective layer, and would turn them earthwards. It was a theory difficult either to prove or to disprove, and the voyage of sound-waves into the Upper Atmosphere remained barren of discovery, until the solution of



VARIATIONS OF TEMPERATURE
AND PRESSURE WITH HEIGHT

the riddle was found in an unexpected quarter.

When Columbus set out to make a voyage round the world he failed in his objective, but he discovered America. It is a typical example of what happens in the case of scientific research. On the subject of sound-waves research continued to be carried on with little success, but meanwhile research on the subject of meteors and shooting stars provided the clue to the unaccountable behaviour of sound.

In 1923 two English scientists, Lindemann and Dobson, published a paper in which they stated that they had reached the conclusion that the luminosity of meteors must be produced by a density of atmosphere at certain high levels greater than current theory had allowed. From this they inferred that the air below these levels must be buoyant, and that the buoyancy must be due to an increase in temperature at a height of about 30 miles above the earth's surface.

Meteors have no direct connection with the subject of sound, but in the discovery of the high temperature at this altitude lay the clue to the mystery of the returning sound-waves. If they had travelled through the stratosphere as far as this region in the straight line conditioned by a constant temperature, their velocity would be immediately increased by the change in temperature, and they would be turned back towards the earth, passing, as on their upward journey, in a straight line through the lower stratosphere, and in a concave curve downwards through the troposphere, until they reached the ground again in the zone of abnormal audibility. Further observations made first by ear and then by Kühl's radiograph confirmed this theory, but indicated that the transition from the lower to the higher temperature came lower in the stratosphere than Lindemann and Dobson had suggested. Research was carried on both in England and on the Continent, and when the hot-wire microphone came into use the information collected became far more accurate. We all know how, when we blow upon a glowing coal, the glow immediately becomes brighter, and when we cease to blow the glow becomes dull again. This, in simple terms, is the principle of the hot-wire microphone, and the sensitivity of the hot-wire is so great that sound-waves impinging upon it from nearly 200 miles away cause an appreciable variation in its glow. These variations can be photographed, and in this way an accurate record may be kept even of sound-waves that are inaudible to the human ear.

In 1927 F. J. W. Whipple was enabled, by courtesy of the British Admiralty, to systematize research in England. He enlisted the co-operation of five university laboratories, in each of which he installed microphones of this type, and records are now kept of sound-waves sent out by the firing of heavy guns at Yantlet (Isle of Grain), at Shoeburyness (at the mouth of the Thames), and at Woolwich. During the firing signals are broadcast, superimposed on the ordinary radio programmes, at Woolwich simultaneously with the discharge of the gun, and at Yantlet and Shoeburyness after a known interval. Generally three microphones are used in connection with each recording instrument, so that the direction from which the sound-waves are coming can be ascertained, and the angle of descent may be estimated.

The places at which these sound-waves are recorded are the following, and the distances given are from Shoeburyness to the nearest recording microphone at the station mentioned:

Nottingham	129 miles
Birmingham	133 miles
Bristol	148 miles
Sheffield	160 miles
Cardiff	167 miles

Calculating from the average speed of sound-waves, the sound of an explosion should reach Nottingham from Shoeburyness in 10¾ minutes; actually there is generally a delay of about 100 seconds, and the delay at the different stations is proportional. This delay shows that the sound has not travelled all the way in the air near the earth's surface, and careful calculations, which take into account both the angle of ascent and the angle of descent, indicate that the path of the waves extends a considerable distance into the stratosphere.

On one occasion, in October 1930, a delay of 200 seconds was recorded in the reception at Nottingham, and it is supposed that this was caused by the fact that the waves had travelled twice into the stratosphere, having been reflected from the ground at an intermediate point, a phenomenon which had often been observed on previous occasions in Germany.

The main facts about the nature and behaviour of sound-waves as far as they had been ascertained previous to the war have already been outlined. It will be seen from the short account that has been given of research which has been carried on during the last dozen or so years that to these facts three others of considerable importance must be added. In the first place the existence of a definite zone of silence has been established. It has already been remarked that Pepys knew of its existence nearly 300 years ago, but there is sometimes a big discrepancy between popular knowledge and scientific fact, and, shrewd observer though he was, we may not accept Pepys's unsupported testimony as final except perhaps on the subjects of velvet coats and female beauty. There we accept his authority as supreme, but on the question of the audibility of sound we are glad of further evidence. This has, in this instance, confirmed his statement, and, in addition, the occasional presence of a second zone of silence and of two possible zones of abnormal audibility has been proved, and their probable average area ascertained.

In the second place a seasonal variation in the distance of the first zone of silence from the origin of the sound has been noticed. This distance varies from a mean of 69 miles in winter to a mean of 105 miles in summer, and is probably due to the seasonal difference in the density of the atmosphere. In cold weather the molecules of which the atmosphere is composed are more closely packed, and therefore the sound-waves that travel near the earth's surface are more rapidly absorbed and are able to make only a comparatively short journey. In warm weather the molecules are farther apart, and so spread over a greater distance; consequently the sound-waves have farther to go before they have encountered a sufficient number of molecules to absorb them. This seasonal difference emphasizes a point which has perhaps not been made quite clear, namely that it is actually because sound-waves ascend into the rare atmosphere of the stratosphere that they are able to travel so great a distance from their source without being absorbed. If their journey were accomplished in the dense atmosphere near the earth's surface it would of necessity be a much shorter one. .

Thirdly, the variation in the delay of the reception of sound-waves indicates that their path is not always uniform. In covering the distance between the origin of the sound and the recording station they may make one long flight through the stratosphere, or they may make two shorter flights, coming down to earth between the two flights. The difference made by the variation of route in the distance they travel will be considerable, for in the first instance they make one ascent and one descent, in the second two ascents and two descents, and on each occasion they must rise as high as the region of higher temperature before they can come down again. The height of this region is, however, itself variable, and changes both with latitude and with time of year.

And this brings us back to the main object of this investigation of the voyage of sound-waves, which was undertaken with the intention, not only of discovering the route they followed, but also of exploring the nature of the region through which they passed. About this region the voyage of sound-waves proves one important fact, and that is the hitherto unsuspected rise in temperature in the upper stratosphere, where formerly, following the theory of Tessereinc de Bort, the temperature had been believed to be uniform. This rise in temperature has an important bearing on other problems, one of which was suggested by Lindemann and Dobson, namely the existence of an ozone layer in the stratosphere. We must allow to sound-waves the honour of giving valuable support to the theory of the existence of this layer, but we must at the same time admit that, fruitful though their voyages have been in suggestion, the information they have brought back to earth on this particular subject is meagre. Exploration of the Upper Atmosphere, like that of the earth it enfolds, cannot be completed by one vessel only. Magellan must follow Columbus, we must have Vasco da Gama as well as Bartholomew Diaz. We give sound-waves due acknowledgement for their contribution to our knowledge of the Upper Atmosphere, and then turn to the history of other voyages of exploration for further facts.

Chapter Four

Ultra-violet Rays and their Discovery of the Ozone Layer

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The process of radiation is, in essence, the transfer of energy from one material body to any other material body without the agency of any intervening material medium. The material bodies in question may be solid, liquid, or gaseous, and as far as is yet known the transference is made by what corresponds, as nearly as we can at present determine, to a series of waves, differing in length according to the quality of energy, and travelling through some unknown medium, which has variously been described as the ether, the field, or, the designation adopted by Einstein, space.

The penetrating power of these rays varies enormously, but not uniformly in proportion to their length. The long waves commonly used for alternating currents of electricity can penetrate most solid substances with the exception of some, such as rubber and porcelain; Hertzian, or radio-waves, which may be only slightly shorter, can also penetrate solid substances; so also, to a lesser degree, can infra-red rays. The waves of visible light, which are next in order of length, are brought to a standstill by substances which we commonly classify as opaque, but penetrate with ease and little loss of energy through glass; the penetrating power of ultra-violet rays is small, and they are effectively stopped by water vapour, an ordinary sheet of glass, and many other things. On the other hand X-rays, which are still shorter, can pass through human flesh or leather, but are absorbed by metal, and the heavier the metal the more readily are they absorbed. The gamma-rays of radium have still greater penetrating power, and cosmic rays, the shortest of those here mentioned, are able to penetrate through many feet of lead.

In order to explain clearly the differences in the wave-lengths of light, both visible and invisible, the atom, the spoilt darling of popular physics, who has for long been rustling impatiently at the manuscript pages, must be introduced. Most people are familiar with her, but for the sake of lucidity it is as well to describe briefly her structure.

She has been likened by Professor Eddington to a little lady in crinolines, and the analogy, if not altogether apt, is apt at least to lodge firmly in the memory. The little lady herself—how minute she is! she must exist in a crowd of at least fifty before she becomes visible even through the lens of an ultra-microscope—consists of a nucleus composed of protons and neutrons around which electrons revolve at varying distances and in varying paths. (We must forget the analogy for a moment, for such behaviour on the part of crinolines would surely be embarrassing!)

Electrons are the smallest obtainable negative charges of electricity; protons, which have the same charge but of opposite sign, are hydrogen nuclei, and are very massive compared with the electrons; neutrons, which have only recently been discovered, are very close combinations of protons and electrons; that is, each neutron consists of a proton-electron pair of very small size, millions of times smaller than the normal hydrogen atom. Until recently the nucleus of an atom was said to consist of protons and electrons, but nowadays it is believed that no unassociated electrons occur; therefore the nucleus of any atom may be said to consist only of protons and neutrons.

Each atom in its normal state contains an equal number of protons and electrons, and hence the complete atom is always neutral. If, however, for any reason it loses one or more of its outer negative charges, it becomes a charged atom, or ion. The little lady may be clad in the most modern manner and wear only one skin-tight, revolving petticoat. She is then an atom of which hydrogen is the typical representative. She may, on the other hand, be clothed in crinolines in more than

Victorian abundance, each revolving in its own orbit at its own prescribed distance from the nucleus. The atom which composes mercury has no less than eighty electrons; but, although the nucleus itself becomes weightier in proportion to the increase in the number of its encircling electrons, she can hardly be said to be over-clad, for the weight of an electron is only one-one thousand, eight hundred and fortieth part of that of the proton—gossamer clothing at best.

We shall come back to this little lady in a later chapter on ionization, but in the meantime we must forget her and refer, in a more serious vein, to protons and electrons. Radiation is caused by the fact that the atom becomes excited—the phrase is a properly scientific one—and one of its electrons jumps for one thrilling ten-millionth of a second beyond its proper orbit, and then returns to its place again. In this way energy is lost to the atom, and is sent out in the form of transverse waves through space. When the disturbance is caused amongst the inner rings of electrons more energy is released, the waves vibrate more rapidly, and are consequently shorter; when the change of orbit occurs amongst the outer rings of electrons less energy is released, the waves are of lower frequency and consequently longer. The length of a wave, in this sense, is the distance between crest and crest, which is of course determined by the rapidity with which the waves are set in motion.

It is a truism of physics that energy is never lost, but only transformed. Conscienceless little Ariel sang more truly than he knew

> 'Nothing of him that doth fade
> But doth suffer a sea-change
> Into something rich and strange.'

It is true of all things, and it is true of the energy lost to the atom. It is like a splash—how small a splash is beyond the grasp of imagination—that sends out waves that continue to travel in a definite direction, either until they meet something that will cause them to bend, or until they encounter some transforming substance.

It is this bending of rays which explains the spectrum. When white light passes through a prism the rays of which it is composed are bent, but they are not bent uniformly. The longer rays of which red light is composed are bent only slightly, those which compose orange light are bent a little more, and so on through the colours of the spectrum, yellow, green, blue, and indigo, until we reach the short waves of violet light which are bent most of all. In this way the difference of angle has the effect of sorting out the rays, and in the place of white light we see the colours of which it is composed. It is also possible to reverse the process by refocusing the colours of the spectrum by means of a glass lens, so that a white spot of light is again formed. This effect can also be produced by a revolving disk on which the colours of the spectrum have been painted in their correct proportions. When such a disk is revolved with sufficient rapidity the colours disappear, and the disk appears white, or rather, since the colours of paint are not so pure as those of light, a whitish grey.

It is a mistake to think of all light as visible to the eye. If the eye were sufficiently sensitive that might be so, but actually the eye is only sensitive to light within a certain range of vibrations. (If tradition be correct a cat's eyes are sensitive to a somewhat longer range.) This fact is easier to understand when we remember that in the case of the sense of smell a dog's nose is sensitive to scent which for us does not seem to exist, though we are readily enough convinced of its existence by the behaviour of the dog. Another similar example is the fact that, as we have shown, sound-waves inaudible to the human ear can be detected by a hot-wire microphone.

Visible light ranges from the waves that form red light, which have about 400 billions of vibrations per second, to those that form violet light, waves of about 800 billions of vibrations per second. These, however, can only be detected on a very clear day and in the most favourable circumstances. The photographic plate is able to record infra-red rays down to 300 billion vibrations per second, and the spectroscope, an instrument that consists principally of a prism of quartz or fluorite spar and a number of powerful magnifying lenses, records still lower down the scale.

At the other end of the scale the spectroscope also records rays beyond those of visible violet light, which are known as ultra-violet rays. These are of a higher frequency and of a shorter wave-length than that of visible light, and are present in the spectrum produced both by sunlight and by synthetically produced or artificial sunlight. It is well known that the sun emits rays of a far shorter wave-length than that of the ultra-violet rays; nevertheless in the spectrum produced by natural sunlight the ultra-violet limit is reached with extraordinary abruptness, which is not the case when the spectrum is produced by artificial sunlight. In 1880 Hartley suggested that this abrupt limit was due to the absorption of these shorter rays by ozone in the earth's atmosphere.

Scientific speculation on the subject of ozone has given rise to the popular belief that it is possible to go to the seashore and breathe it in in lungfuls, but the actual fact is that at the earth's surface it exists in such infinitesimal quantities that it almost defies detection. The supposition then amongst physicists was that if it existed in appreciable quantities it must be at some distance above the earth.

The fabulous qualities popularly attributed to ozone probably originate in its actual and very real relationship to oxygen, for it is formed from that element by the action, in regions of low temperature, of extreme ultra-violet radiation. The effect of this radiation is to combine three atoms of oxygen in such a way that a molecule of ozone is formed, but the existence of these ozone molecules is very precarious, and can be constant only in very low temperatures, for in ordinary temperatures, such as those of the lower atmosphere, they tend to revert to oxygen. Impermanence is the very nature of ozone, and its peculiar characteristics are the means of its own destruction, for as it absorbs radiation—not only short ultra-violet but also long infra-red—and emits very little indeed, it inevitably creates that higher temperature in which it tends to lose its individuality and resolve into its component oxygen atoms again.

In 1913 Fabry and Buisson in the *Journal de Physique* stated definitely that ozone existed in some considerable quantity in the earth's atmosphere, but the chemical methods available at the time were unsatisfactory, and consequently their results were inconclusive. By the year 1920, however, spectroscopic methods had come into use, and light could be analysed into its constituent colours, measured, and its ultra-violet limit accurately determined. With the more efficient means now at their disposal Fabry and Buisson were able to establish the fact, which further research has confirmed, that ozone exists somewhere in the atmosphere in a quantity equivalent to a layer varying in thickness from one-sixteenth to one-seventh of an inch at atmospheric pressure, that is to say, if it were taken down to the level of the ground.

It was again Lindemann and Dobson, in their investigations on the subject of meteors, who, providing yet another instance of the way in which the scientist looks for one thing and finds another, furnished the clue to this problem of ozone.

It has already been mentioned in the previous chapter that their observations of the height at which meteors became luminous led them to believe that the temperature of the stratosphere could not be uniform, as available measurements had led scientists to suppose, but must increase at a certain level. They suggested that this increase might be accounted for by the presence, at a certain high altitude, of a belt of ozone, by which radiation would be absorbed to a much greater extent than it would be emitted and which would in this way raise the temperature of the atmosphere. Ozone may be formed either by electrical discharges from thunderstorms, or in polar lights, or by ultra-violet radiation. In this case they thought that neither thunderstorms nor northern lights could be held accountable, and they concluded that the layer of ozone must owe its origin to large quantities of ultra-violet radiation, and must therefore lie in the upper stratosphere, at the height, in fact, at which sound-waves are turned back to earth.

Dobson decided to make regular spectroscopic measurements of the ozone in the atmosphere, and with this end in view he constructed a special spectroscope which he set up at Oxford. Owing to the fact that the earth is round, the solar spectrum can be measured at different angles as the sun rises to the zenith and declines towards its setting, and by comparing the differences in its ultra-violet limit as recorded at different altitudes both the height and thickness of the ozone belt can be determined.

Dobson's experiments established the fact that its height is about 30 miles above the earth's surface, and that its average thickness must be equivalent to about one-eighth of an inch at atmospheric pressure, with considerable variations from day to day.

Having discovered so much he went on to investigate the relation between the varying thickness of the layer and atmospheric pressure at the earth's surface. This necessitated the carrying-on of observations at various stations, and Dobson proceeded to construct a number of spectroscopes which he distributed over Europe. The results of the experiments which followed established some interesting and surprising facts. First that there is an intimate relationship between the concentration of ozone, 30 miles away in the upper stratosphere, and pressure distribution at sea-level; and secondly that the relationship is an inverse one. Regions of high concentration of ozone travel above, though slightly in the rear of, regions of low pressure, and regions of low concentration of ozone travel, again a little laggardly, above regions of high pressure; or, to put it a little differently, the celestial camp-follower of a cyclone is a region of high concentration of ozone.

Dobson then redistributed his spectroscopes in order to discover the variations in the quantity of ozone with latitude and with season, and this time he established them at stations as far apart as California and Egypt, Switzerland and New Zealand. These experiments led to another surprising discovery: that, in spite of the fact that the formation of the ozone layer was thought to be due to ultra-violet radiation, ozone is far more abundant in polar than in equatorial regions. Its seasonal variation is small in low latitudes, but considerable in polar regions, where it reaches its minimum in the autumn, and its maximum in the spring at the end of the long polar night. It seems that it is not to the seaside that we must go in order to breathe in ozone, but to some region above the pole, which is certainly less likely to be overcrowded than Blackpool or Brighton.

This discovery lends colour to the suggestion that the ozone layer does not, after all, owe its existence to ultra-violet radiation alone, but may also have some connection with electrical discharges from the aurora. The aurora, however, is a phenomenon so beautiful and fascinating that we must do it what homage we can by paying it the tribute of a special chapter.

Before leaving the subjects of ultra-violet radiation and ozone we might perhaps be permitted to leave the exploration of the Upper Atmosphere for a moment and digress into some account of the effect of each on life in this air-enfolded planet.

The ozone layer, far removed from us though it is, has an influence so considerable that, if it did not encircle the earth and act as a gigantic filter for the radiation hurled at us by the sun, life would be extinguished by the excessive quantity of ultra-violet rays that we should receive. The effect of unlimited solar radiation would be fatal, and this layer of ozone, no thicker than a wafer biscuit, is all that stands between us and speedy death.

On the other hand it is a well-known fact that a certain amount of ultra-violet radiation is beneficial, and even necessary to life, and if the ozone layer were to become so thick that this little necessary quantity could not penetrate it we should all suffer from rickets, and probably in that way come to an untimely end.

In passing, it may be noted that the type of lamp often used in sun-ray therapy actually does give out radiation which at the ultra-violet end resembles that of unfiltered sunlight. The use of a lamp of this kind may be dangerous, and the reason that ill effects do not more often follow is that the radiation is generally weak. The remedy to this fault is very simple, for several types of glass (such as Vita-glass) are manufactured, which when used with the lamp act as a filter, as does the ozone layer to sunlight, and allow only the beneficial rays to pass through. The ideal lamp, of course, would include infra-red rays as well as short ultra-violets, duly filtered. In the light of such a lamp we might bask as in real sunlight, and become sunburnt in as much comfort as on the Lido.

The fact of the absorption of ultra-violet radiation by water vapour is far more widely known than that of its absorption by ozone, and nobody nowadays needs to be told that on a day of dark clouds we do not get our ration of 'ultra-violets'. But it is not so generally known that the quantity of water vapour contained in the atmosphere has varied considerably at different periods of the earth's history, and has had a corresponding influence on life. It is almost pathetic to think of the ichthyosaurus and the mastodon wilting away for lack of ultra-violet rays, and yet it has been suggested that such may have been their fate. A considerable temporary increase in the quantity of water vapour surrounding the earth may possibly have been the cause of their extinction, and had it been possible to have them treated by artificial sunlight we might have had some of them with us yet.

Sun-ray radiation alone, however, might not have been sufficient to save the saurians. There is a close relationship, not popularly recognized, between diet and ultra-violet radiation. Each without the other proves ineffective.

If we compare the children in the Faroe Islands, which lie in the Gulf Stream, and therefore in spite of long summer days are frequently enveloped in mists, with the children in Iceland, which is scarcely touched by the Gulf Stream, and in spite of long winter nights is almost free from mists, we find that rickets is very prevalent in the Faroe Islands, and almost absent in Iceland.

In these two cases food has little to do with it, for it is substantially the same, consisting of raw fish, whale flesh and oil.

But if we pursue our enquiries a little further and compare the condition of the children in Greenland with that of the children in Labrador we cannot make the same inference. In Greenland and Labrador the climate is almost identical, each country is blessed with sunshine, and receives its full ration of ultra-violet radiation. But in spite of healthy climatic conditions a very high percentage of the children of Labrador suffer from rickets, whilst in Greenland the percentage is extremely low. In this instance the secret of the difference lies in the quality of the food. Greenland is as yet little affected by civilization. Food consists of raw meat and fish, and children are suckled until they are running about and taking solid, in addition to liquid, food. Into Labrador, on the other hand, civilization has introduced tinned foods in great quantities, as well as cereal foods, and the unwholesome habit of cooking before eating. It is the children that suffer.

These facts prove that ultra-violet radiation alone is not enough to produce a healthy race. It must always be allied to the right type of food, that is to say, food that contains vitamins of all kinds in adequate quantities. We will not point the moral too sharply, for civilization has enough blows aimed at its threadbare back, but it is as well to remember that cooking is almost as fatal to vitamins as lack of 'ultra-violets' to the saurians. It is evident that life exists on this planet very precariously, and it is a miracle that it exists at all. We are helpless to regulate the thickness of the ozone layer on which our life depends, but we may possibly have a little more control over the use of the gas cooker.

Chapter Five

The Paths of Radio-waves

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The atom is, without doubt, the leading lady of physics, and like all leading ladies she must be given a prominent part; so we will allow her to make her second entrance at the beginning of this chapter in spite of the fact that its real subject is the exploration of the Upper Atmosphere by means of radio-waves; they must be kept waiting in the wings whilst the atom, complete for the moment in crinolines, makes her second appearance.

We have already referred to her as a Victorian lady, with a stout heart enveloped in crinolines of electrons of more than gossamer lightness. We might indeed have likened her to a ballet-dancer but for the fact that her behaviour is more like that of a highly respectable Victorian matron, who doffs her shells of electrons with exemplary reluctance. She may be persuaded to part with the outermost without too much difficulty in a case where, as in the atom which composes gold, she is abundantly clad; just as a Victorian lady, after a show of resistance, may lay aside her shawl.

To discard her second shell of electrons, she requires more persuasion—a draught is a terrifying danger—and in order to divest her of her third, extreme violence may be necessary. In fact the atom is so essentially Victorian that it requires the utmost skill to divest her of her most intimate garment, and even then she will begin to gather her scattered electrons round her again without delay directly the violence which deprived her of them ceases.

We are here, of course, describing a laboratory experiment—you are as little likely to meet a naked nucleus outside the laboratory as you would have been to meet a lady walking the streets in a state of nature in the days of the Good Queen—and the process is known as ionization. When one electron has been removed the atom is singly ionized, when two electrons have been removed she is doubly ionized, and so on until, when her last garment has been wrenched from her, you have, in the heartless phrase of the physicist, the stripped atom.

In the laboratory ionization is effected either by bombarding the atom with X-rays, or by causing collisions between fast-moving electrons and atoms. In each case the nucleus is stripped of one or more electrons, and these electrons are shot off at an extremely high velocity. But even under this purposeful bombardment only a very small proportion of atoms become ionized; the rest maintain their integrity, and at the same time the few free electrons show a strong tendency to incorporate themselves with any available incomplete atom. It must be remembered that free electrons are electric charges, and that when they are present in considerable numbers they form a medium of high conductivity for electric currents or radio-waves.

And now, having allowed the ubiquitous atom to have her say and to explain the process of ionization, we can start in earnest on the subject of radio-waves.

Although it was Hertz who, in 1883, actually demonstrated the possibility of creating electric waves that travelled in space, he was only following out a suggestion made previously by Fitzgerald that such an achievement ought to be possible. The difficulty that Hertz encountered was not so much that of producing these waves as that of detecting their presence when produced. Eventually, however, he succeeded in devising both a radiator, the apparatus which, by generating an oscillatory electric current, produces the waves, and a resonator, an apparatus for detecting them. In that hour wireless telegraphy, a feeble and unpromising infant at first, which was yet destined to develop into the wireless telephony of to-day, was born.

Branly of Paris is deserving of mention for having invented, in 1892, a new and more efficient type of detector. Four years later, in 1896, Marconi, with a still further improved detector and a new type of radiator, made of wireless telephony a practical achievement.

Hertzian, or radio-waves, as they are now called, have essentially the same character as light-waves. They are transverse, and travel at the same speed and in the same medium, that which we follow Einstein in calling space, rather than the ether or the field. Hertz proved that they could also, like light-waves, be reflected or refracted by mirrors or prisms, a process of the greatest importance in the later development of wireless telephony. The wave-length of radio-waves is, however, far greater than that of visible light or even that of infra-red waves.

The history of the discovery of an ionized layer, now known as the ionosphere, in the Upper Atmosphere, is bound up with the history of radio-waves. In 1882, nine years before Johnstone Stoney first gave the electron its name, Balfour Stewart, whilst investigating the variation of the earth's magnetic field, pointed out that some such layer of high electrical conductivity must exist. Ten years later Oliver Heaviside suggested that the process of ionization, possible in the laboratory, might also be going on somewhere in space, and that this process of ionization might create the layer of high conductivity postulated by Balfour Stewart. It was eventually, however, by the study of the paths of radio-waves that it became possible to reach a confirmation of the theory.

How is it that radio-waves sent out from a transmitting station, and travelling, as they do, in straight lines at a speed of about 186,000 miles per second (or about 1000 feet in one-millionth of a second), do not eventually leave the curved surface of the earth and vanish for ever into space? It is the same riddle as that which arose in connection with sound-waves, but the same answer does not apply, for radio-waves do not travel through the medium of air, and their speed is not affected by temperature. Messages might be received in Mars, but there is no obvious reason why they should be received on earth any farther from the transmitter than they can travel on, or just above, the earth's surface, for radio-waves are not capable of curving sufficiently to enable them to follow the spherical shape of the globe. Somehow and somewhere they must be turned back from their voyage towards outer space in such a way that they can 'put a girdle round about the earth' in far less than Puck's laggard 40 minutes. A radio-wave can encircle the globe twice, taking about one-seventh of a second for each journey. But it is difficult to believe that Puck allows himself to be so outpaced, and no doubt in this age of swift travel he has vastly improved upon his leisurely Elizabethan record.

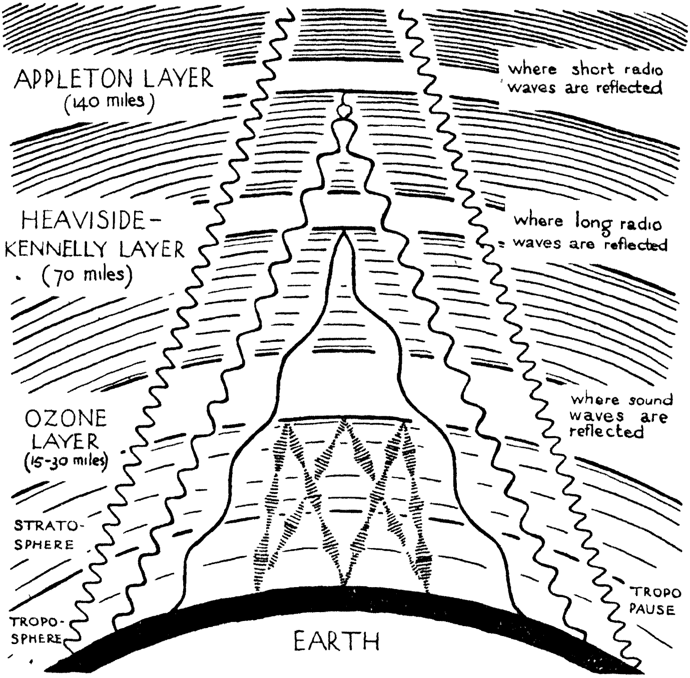
In 1902 Kennelly and Heaviside insisted that there must exist in the Upper Atmosphere a region of high electrical conductivity, an ionized layer in which free electrons would increase the speed of radio-waves and turn them back to earth. This theory, although it was not actually proved beyond question until more than twenty years later, was generally accepted, and the ionized layer became known as the Heaviside layer.

The ionization of gaseous atoms in the atmosphere may be effected by several means, all of which correspond to some extent to the processes described in the laboratory. It may be caused by a bombardment of rays, either solar ultra-violet radiation, solar gamma radiation, or cosmic radiation. This process corresponds to the X-ray bombardment of atoms in the laboratory, and differs from it mainly in that the bombardment in the atmosphere is incomparably the more powerful.

It may also be brought about by a process of collision. The sun emits both free electrons, which travel at great speed and are known as cathode rays, and also material particles. Either of these may ionize the gaseous atoms with which they come into violent contact.

Near the earth's surface yet another process of ionization goes on. The earth's crust contains what are known as radio-active substances, such as uranium, thorium, and ionium, which emit material particles (alpha rays or helium nuclei) fast electrons (beta rays), and short-wave radiation (gamma rays), all of which act on the atom as ionizing agents. Their effect, however, is only appreciable in the atmosphere close to the earth, and decreases rapidly with height, whilst over ocean surfaces it is negligible.

With the object of deciding between two opposing theories, the one that the Heaviside layer owes its existence mainly to a stream of swiftly moving corpuscles sent out by the sun, the other that it is mainly due to ultra-violet radiation, an experiment was carried out during the eclipse of the moon in 1927. If the reflecting layer were due to cathode rays, which have a velocity much less than that of light, from the point of view of reflected radio-waves there would be not one eclipse, but two, since the shadow, or rather shield caused by the cutting-off of the cathode rays, would move more slowly than that cast by the cutting-off of the swiftly moving ultra-violet rays. The result of the measurements made at the time was in favour of ultra-violet radiation, and there



THE PATHS OF RADIO AND SOUND WAVES

This representation is diagrammatic. The waves do not travel upward at this steep angle, and in the upper layers they travel nearly horizontally for some distance.

is little doubt that this is the ionizing agency in certain definite layers of the ionosphere. But there are variable layers of ionization which may have their origin in such various agencies as meteors and meteoric matter, charged particles emitted by the sun, thunderstorms, and changes in the composition of the atmosphere. When we have taken all these into account, however, we may still consider solar radiation of varying penetration as the principal agent.

This question of the agent responsible for the creation of the Heaviside layer involves also the question of its height, which is not difficult to measure, for the speed of radio-waves is constant, and their angle of ascent and descent can be ascertained. From about 1924 until the present date careful and systematic measurements have been made in England, Australia, and elsewhere, and these measurements have established the fact that there are present in the Upper Atmosphere not only one, but at least three ionized layers, the Heaviside layers, one which forms below it, and one which forms above it, named after its discoverer the Appleton layer. The two upper layers may again be subdivided, and it is probable that yet another definite, but as yet unnamed layer exists between the Appleton and the Heaviside layers.

Radio-waves may be described as travelling round the earth between conducting shells, that of the earth below, and that of the encircling ionosphere above. Incidentally, earth-waves and sky-waves, travelling at slightly different speeds, have a way of interfering with each other, to the great inconvenience of the receiver, a problem which has been the cause of much embarrassment to practical radio experts.

These ionized layers, which vary very much in height both with the time of day and with the season of the year, are now frequently referred to for the sake of convenience as the D, E, and F layers.

The D layer, which is the lowest and forms beneath the E, or Heaviside layer, varies in height between about 25 to 30 miles. It reflects only the longest radio-waves, those of some thousands of metres in length, and even these rarely at any time of the day other than just after sunrise. At other times it acts to some extent as an absorbing medium, and weakens the rays that pass through it to be reflected higher up.

The original Heaviside layer, which is the middle or E layer, varies considerably in height, being, as might be expected, lower in the daytime and in summer, when the ionizing effect of solar radiation is at its height, and higher during the night and in winter-time, when the effect of solar radiation is weakened or removed, and ions and electrons tend to recombine to form neutral atoms, especially in the lower part of the layer, where ionization is always least. Its average height is round about 65 miles, although it has sometimes been known to be as low as 45 miles, and as high as 90 miles. Frequently it falls from about 80 to 70 miles about dawn, but occasionally it remains at a steady height of about 70 miles all night. This layer usually reflects waves of between 300 and 400 metres in length, and the shorter waves tend to penetrate it and are then reflected from the Appleton, or F layer above.

The height of this layer is probably subject to the greatest variations of all. It has been recorded as low as 93 miles in Australia, where a height of 242 miles has also been recorded. On an October night in England it has been known to reach a height of 250 miles. When all the known heights have been examined, however, it seems probable that its average height is round about 150 miles. The F layer reflects waves of about 100 metres in length, and shorter waves are apt to penetrate it into outer space. Waves which are reflected from the F region before dawn are generally reflected from the E region directly after dawn, when the effect of solar radiation immediately becomes apparent in the increased density of the ionosphere. This abrupt alteration in the path of radio-waves is known as the 'jump down'.

It will be seen that the measurements given are so varied that they can do no more than give a general idea of the possibilities of the height of the reflecting layers, and even the average altitudes suggested are no more than a probability. If we think of the matter in general terms we may picture a bright hemisphere moving from east to west with the passage of the sun, in which the encircling ionosphere approaches the earth, followed by a dark hemisphere where recombination is taking place, and in which the ionosphere recedes from the earth.

Up to this point we have given some account of the path taken by radio-waves of 100 or more metres in length, and have merely remarked that there are shorter radio-waves which pass right through the ionosphere. Of these unreflected waves the greater number are lost to us; they pursue their journey into vast unknown regions, and we know nothing of what becomes of them. They may be received on some other planet, on Mars perhaps, if apparatus is available. Mars is cooler than the earth and its habitable period has therefore been longer. Supported by this fact tradition has it, nor is it difficult to believe, that the Martians far excel in intelligence the inhabitants of the earth, and they may already be picking up and translating our stray messages. But this is only a conjecture in the vein of Jules Verne. No less fantastic, though it is sober fact, is the story of those short radio-waves which, in certain circumstances, are not lost to us. After penetrating the ionosphere they voyage, it may be as far as the moon, it may be more than ten times farther, and then return to earth, where they are received as echoes some seconds after the original signal. This statement sounds as incredible as the suggestion, admittedly a fanciful one, that earth signals may be received on Mars, and it is only fair that some account should be given of the actual, scientifically established facts.

The phenomenon was first observed towards the end of the summer of 1927 by a wireless enthusiast, Jörgen Hals, of Bygdö, near Oslo, who found that in addition to the short-wave signals sent out from Eindhoven in Holland he occasionally received not only the earth echo, which at that distance would arrive about one-seventh of a second after the original signal, but also another echo 3 seconds later, for which he was at a loss to account. He could, literally, hardly believe his ears, for, allowing for the normal speed of radio-waves, these 3 extra seconds implied that this echo must have made a journey of some 558,000 miles before it reached him.

He communicated the facts to Professor Carl Størmer, who was so interested that he made arrangements for regular short-wave signals to be transmitted from Eindhoven for experimental purposes. Of these signals a film was made, but the results were unsatisfactory and inconclusive, and the question would probably håve been dropped had it not been for an interview at Eindhoven between Størmer and van der Pol, of Phillips Radio, in which van der Pol's enthusiasm put fresh life into that of Størmer, and it was decided that further experiments should be made in the autumn of 1928. It was arranged that a signal of three dashes on a certain note should be transmitted on a wave-length of 31.4 metres at stated intervals from Eindhoven, and that, as Størmer lived quite near to Hals, the latter should immediately communicate with him on the telephone if abnormal echoes were audible.

Experiments recommenced on September 25th, 1928, and on October 11th, in response to a telephone call from Hals, Størmer hurried to his house to hear on entering both signals and echoes so clearly reproduced by the loud speaker that they were audible all over the house. The note of the echo was the same as that of the signal, but occasionally the dashes were slightly prolonged so that they overlapped each other, and the echo was then more long drawn out. The interval between signal and echo varied between 4 and 15 seconds, the average interval being about 9 seconds.

Further successful experiments were carried out, organized by Ober-Ingenieur Hermod Peterson at a series of receiving stations between southern Norway and Spitzbergen; similar observations were made by Appleton and Borrow in London during February, 1929; and perhaps the most interesting results of all were obtained by von Galle and Talon in French Indo-China between the 8th and 10th of May, which was the time of the sun's eclipse, the total eclipse occurring on May 9th, 1929.

No doubt remains possible as to the facts. Echoes were recorded as before in Norway; in London they were heard distinctly 25 seconds later than the original signals; in Indo-China about 2000 echoes were recorded, some of them with an interval of 30 seconds between signal and echo. It must be remembered that we are dealing, not with sound-waves which travel through air at a leisurely speed of one-fifth of a mile per second, but with radio-waves which travel through space at a speed of 186,000 miles per second, and that therefore this interval of 30 seconds signifies that these radio-waves had accomplished a journey of 5,580,000 miles, eleven times as far as the moon and back again.

The figures are so amazing that it is not surprising that it is difficult to find a plausible theory to account for them. Størmer, who has done much research in connection with polar lights, believes that, owing to the action of the earth's magnetic field, between the zones in which polar lights are usually observed there lies a region, which can best be described as a gigantic hollow ring encircling the earth, within which there is no corpuscular radiation. This ring, according to Størmer, is enclosed within radiating walls formed by streams of electrons, or cathode rays. He suggests that the radio-waves that are responsible for the echoes which have just been described penetrate the ionosphere somewhere within this ring, and are then free to continue an uninterrupted journey until they encounter its reflecting walls, whence in favourable circumstances they may be turned back to earth.

Hans Dostal, however, points out that, on account of the immense distances traversed by some of the waves, the theory of circular reflecting walls must be modified, and he suggests that the sun emits, not formless masses of cathode rays, but ribbons, or streamers, the inner surface of which acts as a reflecting layer, and when encountered by radio-waves turns them back on their course, and focuses them on to definite places on the earth.

We need pin our faith to no theory, but we may, and in fact must, accept the fact of the existence of these echoes, which are known to German physicists as 'world-space echoes'. Their existence is proof that certain short radio-waves sent out from transmitting stations on the earth go voyaging millions of miles through space, and then turn back towards our planet, a small object in so vast a region; those that succeed in finding it are caught by receiving stations, and revert at last to audible sound.

Beside such facts messages to Mars, which is only 34,600,000 miles away, would hardly look like a miracle.

Chapter Six

Projectiles in Space

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When we see a shooting star fly through the night sky we wish, and in that moment we believe that the wish has wings that bear it high above the plodding path of reason. Beatrice was born in a merry hour, and she declared that her feather-shafted wit was due to the fact that in that hour a star danced. And indeed who can watch a star fall through the heavens without feeling a lilt of joy at the heart which the swiftness of its passing has no power to suppress? But our joy would be shortlived if, when we looked up into the sky again, we found Vega missing from the Lyre, or Orion doomed to pursue the celestial hunt without his faithful attendant Sirius.

We need fear no such misfortune. Nature is not so poor that she must rob the constellations in order to provide us with a display of shooting stars. Such a proceeding, were it necessary, would prove highly dangerous, for who knows what stars might collide, and annihilate each other? It is just as well for us earth-dwellers that the average shooting star, for all the brave show it makes, is actually no bigger than a pea, and that only very few are more than a few pounds in weight.

A shooting star can hardly, in a literal sense, be called a star at all; it is merely one of a meteoric swarm which encounters the earth's atmosphere with such velocity that both the meteor and the air compressed in front of it become heated by the friction, the surface layers liquefy and vaporize so that a cloud of incandescent vapour spreads around and trails behind it. It is this enveloping incandescence that we see in the form of a shooting star by night, or, less frequently, as an evanescent wisp of cloud in the daytime.

The majority of shooting stars burn themselves out before they reach the earth, but if that does not happen their velocity is so much checked by impact with the constituents of the atmosphere that they fall harmlessly into the ground, so harmlessly that one that fell on a frozen lake in Sweden in the year 1869 scattered its fragments on the ice without damaging the surface. If a shooting star is unusually large it is called a meteor, and if it succeeds in reaching the earth it is known as a meteorite. The majority of meteorites are only recognizable by their chemical composition, for by the time they have passed through the atmosphere they are little more than dust that can be collected only by means of a magnet. But, small though they are, so many of them fall on the earth, no less than several millions every 24 hours, that their total volume would amount to many tons of matter every year. If it were not for the existence of our protective covering of atmosphere such a bombardment would be truly terrifying, but thanks to the atmosphere there is only one recorded instance of death due to a meteorite.

The velocity with which a shooting star enters the atmosphere is difficult to gauge accurately; it probably varies between 10 to 40 miles per second, that is to say it travels approximately a hundred times as fast as a bullet. Smaller shooting stars become visible at an average height of 70 miles, and vanish again at a height of about 50 miles, after about 35 miles of flight. Larger ones may appear at a height of about 85 miles, and after describing a course which may be as long as 200 miles, disappear about 30 miles above the earth. The time occupied by their flight through the atmosphere is so short that of those that are found just after they have fallen to the ground, in spite of the great heat attained by the exterior, the interior is usually still cold. One that was picked up in India half an hour after it had fallen was actually coated with ice.

Meteoric swarms pursue regular orbits round the sun, and are encountered by the earth, at regular annual intervals, at the point at which the path of the earth crosses that of the swarm. They appear to approach in a radiating shower, but the effect is due to perspective, for their paths are actually parallel. They take their names from the constellation from whose direction they appear to come, and the most widely known are the Perseids, which approach about November 14th, and the Leonids; which approach about November 14th. These showers may last for several days. On November 12th, 1833, the Leonids rained down at the rate of about 200,000 an hour for 5 or 6 hours.

There seems to be some definite relationship between meteoric swarms and comets, and almost direct evidence of this connection has been supplied by the unusually brilliant displays of shooting stars observed in various places in Europe on the nights of October 9th, 1926, and October 9th, 1933. It is probable that these displays are both connected with a comet discovered in 1900 by M. Giacobini of Paris, which he found to be moving in an orbit with a period of something less than 7 years, and at a distance of 5,500,000 miles from that of the earth at its nearest. On the comet's reappearance in 1913 it was observed that its orbit had been altered by planetary perturbation, and that it was one of the few comets that passed sufficiently near the earth's orbit to produce a meteoric shower. If this were correct the date of the display of meteors would be about October 9th, the date on which the orbit of the planet would intersect that of the earth. In 1926, when this comet was again observed, the meteoric display occurred as predicted, on the night of October 9th, and the paths of the meteors were such that it was evident that they were moving in orbits identical with that of the comet. Since the same comet has made its appearance in 1933, and the meteoric shower has occurred punctually and in such profusion as to arouse alarm in the breasts of the superstitious, there seems little doubt that it consists of a swarm of small bodies that the comet has left in its wake. In the same way it is probable that the Aquarids are connected with Halley's comet, and the Leonids with Temple's comet, and consist in each case of showers of matter scattered by the comet concerned. But, although it is likely that meteoric swarms have their origin in the partial disintegration of comets, it does not follow in every case that the comet that gives them birth has ever been of sufficient density to be visible.

The larger meteorites are usually seen between noon and midnight, and, as they must then encounter the hemisphere that is turned backwards from the direction in which the earth is moving round the sun, it seems likely that they overtake the earth on her course, and that therefore the velocity with which they encounter the atmosphere is reduced by the speed at which the earth is moving, namely 19 miles per second. This would account for the fact that they are less liable to be consumed before falling to the ground. The smaller meteorites, on the other hand, are observed between midnight and noon, and fall in the hemisphere that is facing in the direction in which the earth is moving. If they are travelling in a direction contrary to that of the earth, they must dive into the atmosphere with a velocity sufficiently increased either to ensure their destruction or to reduce their size.

The composition of all meteorites is not alike. Most of them are covered with a characteristic black crust, so glossy that it appears as if it has been varnished; beneath this crust some of them are composed of crystalline rock, some of metallic iron alloyed with nickel and cobalt, and some of mixtures of stone and iron.

Meteorites are so often confused with stars, and it is so natural to imagine that their size is comparable, that in refuting this popular fallacy the smallness of the meteorite may have been overemphasized. We need not reject as insubstantial tales, born of ignorance too prone to wonder, legends of fireballs which were larger than the full moon approaching the earth. Such tales are in accordance with fact, even though facts of the kind are rare. Meteorites usually fall to earth in a shower of varying compactness, as a handful of earth may be flung, yet a single mass that weighed no less than 36½ tons was found by Admiral Peary in Melville Bay, Greenland. The largest shower about which the facts have been substantiated fell in northern Siberia in the year 1908. It blasted an area of several square miles, millions of trees were burnt up, and the ground was pitted with craters, many of them as much as 150 feet in diameter, and as much as 12 feet in depth. The sound of the explosion caused by its impact was actually recorded at several meteorological stations in England, but it occurred in so deserted a district that the origin of the sound was not discovered until many years later. The largest compact mass of which anything is known was discovered recently in Arizona by Barrington, and is named after him. It must have fallen some thousand or more years ago, and the event gave rise to strange legends amongst the Indian inhabitants of that region of how the Fire God descended to earth in person with thunder and destruction in his wake. It is estimated that this meteor weighs no less than 10,000,000 tons, and it fell with an impact that buried it in the earth to a depth of over 1000 feet, and made a crater four-fifths of a mile in diameter. No one has as yet succeeded in reaching it, although several attempts have been made, with the object of securing the valuable metals of which the small specimens found in the vicinity give evidence that it is composed. Attempts to sink a shaft immediately above it have been foiled by the presence of water, but further efforts are projected, and there is little doubt that in the course of time it will be unearthed.

In spite of the existence of these gigantic meteors, they are such rare occurrences in the world's history that there is no need to go to bed at night fearing that a similar catastrophe may overtake us while we sleep. Our well-laid schemes may possibly 'gang agley', but it is not remotely probable that we shall be able to lay the blame for our disasters on a meteorite.

We have given considerable space to the subject of shooting stars not only because they are one of the phenomena of nature that rarely fail to stir the heart, but also because they are almost the only travellers in the Upper Atmosphere to which we can with confidence give the name 'projectiles in space'. We might be attempted to apply the term to other very different phenomena, but their journey through space is problematical, and it may be that they are earth-bound after all. These projectiles of doubtful origin consist of masses of ice which are occasionally deposited on the earth, arriving apparently from nowhere in particular. The most natural inference is that they are formed, like hailstones, from the water vapour that is in the atmosphere; but a few meteorologists assert that they are too large for this to be possible, and the theory they advance to account for them is that they travel, as do shooting stars, through outer space, and collide with the earth as they are proceeding on their journey. This theory, however, has encountered weighty opposition and even more weighty silence, and, intriguing though it is, we must be wary of adopting it.

We might mention in passing the shells which the 'Paris Cannon' dropped upon Paris during 1918. With an estimated muzzle velocity of about 2 miles per second these projectiles rose to a height of 34 miles, more than 10 miles higher than the highest sounding balloon. Unfortunately it must be admitted that they gathered little useful information on the journey, and probably it would have been better had the journey never been made. The hiding-place of 'Big Bertha' has not been discovered. Let us hope that she will be allowed to slumber so long that when eventually she sees the light of day she will find, like Rip Van Winkle, that her day is done.

The list of authentic projectiles in space being exhausted we may turn our attention to some imaginary ones, for few of us are not sufficiently human to enjoy seeking the answer tto he question 'What would happen if . . . ?' For instance, what would happen if—shall we say for innocent scientific purposes?—we wanted to bombard the moon? Since the velocity of escape from the earth, that is to say the velocity required to carry a projectile beyond its gravitational influence, is 7 miles per second, the first thing to do would be to construct a gun with a muzzle velocity of over 7 miles per second. Let us suppose, then, that we had a gun with a muzzle velocity of 8 miles per second. The speed of the shell it fired would obviously decrease as it proceeded on its course until it left the rather vague boundary of the earth's gravitational influence at a velocity of 1 mile per second. No sooner would it be free of the earth, however, than it would begin to succumb to the moon's influence, which would gradually increase its speed, so that, there being no atmosphere to contend with, it would eventually reach the moon with the moon's velocity of escape, which is 1½ miles per second, added to its own velocity. In this way a shell that left the earth with a velocity of 8 miles per second would arrive at the moon with a velocity of 2½ miles per second, not so bad a record over a distance of 239,000 miles.

If on the other hand some strange professor in the moon decided, also, we will hope, for purely scientific purposes, to bombard us, his task would be a very different one. The moon is so lightly clad in atmosphere, and her velocity of escape is so comparatively small that 'Big Bertha' would answer his purpose nicely. The shell fired would be beyond the influence of the moon's gravitational attraction much sooner than would be the case if it were fired from the earth, and it would enter the influence of the earth's attraction at a speed of about half a mile per second. And this is where the answer to the question 'What would happen if . . . ?' becomes somewhat complicated. The earth's gravitational pull would increase the speed of the moon-professor's projectile to 7½ miles per second, if it were not for the fact that the atmosphere has to be reckoned with; but, as in the case of the meteor, the resistance of the atmosphere would certainly slow it down. Would it become so heated by friction that it would appear like a shooting star, and be burnt up before it reached the earth's surface, or would it eventually fall to earth at a speed dictated by the opposing influences of atmosphere and gravitational attraction? The solution of this knotty problem would probably depend on the size of the shell. A question of this kind is answered much more easily if, as is usually the case in dealing with velocities of escape, the atmosphere is left altogether out of account. But, as there are at least some five thousand trillion (5.10^{21}) cubic feet of it, it seems a trifle unfair, even if not unscientific, to ignore its presence. In any case it is perhaps just as well that the lack of atmosphere on the moon makes the existence of scientifically minded professors highly problematic.

In the case of a mutual bombardment between the earth and Mars the result is again doubtful. In both directions there is atmosphere to be reckoned with, for Mars is enfolded in atmosphere as is the earth. On the other hand the velocity of escape from Mars is just over 3 miles per second, as compared with our 7, so that in the construction of guns they would have a considerable advantage. Taking into consideration the probability of their superior intelligence it seems best on the whole to hope that, in spite of their name, the Martians are of a pacific disposition.

There was once a little planet called Eros. Its orbit was such that every now and again it approached, astronomically speaking, very near the earth, that is to say within about 16,000,000 miles. Its diameter was only about 15 miles, and its velocity of escape was only about 22 yards per second, so small indeed that children upon it might almost have had a shot at the earth with catapults. It may be that they thought of doing so, for one fine January morning in the year 1932 when it was speeding in the direction of the earth, the planet Eros vanished. It was no more.

And with this cautionary tale we will end a chapter that otherwise has shown an occasional tendency to frivolity.

Chapter Seven

Polar Lights

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'Of all phenomena of nature there is no doubt that Polar Lights, as they are called, are amongst the most beautiful and the most marvellous. On the beholder who is fortunate enough to see them revealed in all their fullness they make an absolutely unforgettable impression. The enigma, the complete mystery of their pageantry has constantly aroused the eager interest of the research worker, and many attempts have been made to explain their actual nature.'[1] Scientists are not usually credited with any near kinship with poets, but this paragraph, written by Professor Størmer of Oslo, reveals a susceptibility which is more often associated with art than with science. Fridtjof Nansen, the explorer and philanthropist, wrote in the same enthusiastic strain. The beauty of these lights which girdle the poles as with fairy rings is, it seems, of such a bewitching quality that under its influence poet and scientist become indistinguishable, and research takes on the garb of devotion.

The known facts about them certainly read like

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[1] 'Über die Probleme des Polarlichtes' in *Ergebnisse der Kosmischen Physik.* (V.W.V., Leipzig.)

a wonder tale. They are connected in some way with the earth's magnetic field, that strange and as yet unexplained influence which affects the needle of the smallest compass, no matter where it may be. They make their appearance in conjunction with disturbances of that 'sphere of influence' which are known as magnetic storms, during which the lines of force become erratic, and may change the direction of the compass-needle by as much as three degrees in as many minutes. Stranger still, they bear an intimate relationship to sun-spots, and during the periods, occurring every eleven years or so, when sun-spots make their appearance with the greatest frequency, magnetic storms also become more numerous, and Polar Lights flaunt in their greatest profusion, responding to the sway, though about a year behindhand, of an unexplained activity of the sun nearly 93,000,000 miles away.

Polar Lights assume an infinite variety of form, but these forms can be classified under general headings, and, although no two displays are exactly alike, there is an order of development which is so frequently followed that it may be considered normal. This order begins with a serene, unicoloured arc of greenish yellow, which may hang motionless in the sky for as long as an hour. After a time its lower edge begins to brighten, and soon afterwards it sends out rays and streamers of red, and green, and violet, and blue, which shoot up in great sheaves to the zenith, or sweep round the sky like gigantic searchlights, or undulate in the form of pendant draperies of gossamer lightness, or whirl in an agitated dance of such wild magnificence that it almost seems as if the heavens would fall. But just as the display reaches a climax it has a way of dying down suddenly, leaving only a diffused light in the sky, from which, as if the Upper Atmosphere is surcharged with electricity, flames again shoot out, waving and pulsating, until they in their turn die down, and the spectacle begins all over again.

Of this complete display often no more than a red glow, as of a northern dawn, can be seen from Central Europe; hence arose the name 'Aurora Borealis', which is adapted to the southern hemisphere as 'Aurora Australis'. It is something of a misnomer, and has to some extent given place to the more accurate appellation Polar Lights.

The separate forms are usually classified under five headings; arcs, rays, streamers, draperies, and diffused light; each of these may appear separately and each presents a different problem to the investigator. The arc, which usually forms the southern boundary of the display, may be no more than a single span curving low over the horizon above a segment of dark sky, or it may consist of as many as nine parallel arches reaching high into the heavens and generally at right angles to the magnetic meridian. It may take the form of a luminous veil, faintly screening the sky at the zenith, more substantial where it reaches down towards the horizon, just above which it stops short and terminates in a low, faintly outlined bow. It may be composed of a diffused greenish-yellow light, or it may consist wholly of rays, slender as glittering silver threads, or bastions of bright spears. These rays may be red where they are near the earth, violet and blue above, or the rays composing a single arc may change from red to yellow, and yellow to red, alternating incessantly. The unicoloured red arc is a rare phenomenon, but it was frequently seen in Europe during the seventies of the last century, a period of frequent displays of Polar Lights. Rarer still is the pulsating arc, which may pulsate from end to end with clock-like regularity, as if animated by an electric current, or at regular intervals of from 5 to 10 seconds may come and go, wholly or in part, with tantalizing evanescence.

Rays, such as those which are emitted by an arc, may also appear separately, and are generally full of colour and movement. They are always parallel to the lines of magnetic force, and therefore the form they assume is largely dependent on the position of the observer. The rays may be short, forming bands or streamers which curve through the sky like prodigious wind-blown pennons, or they may be long, forming magnificent illumined curtains, which wave to and fro, whilst the stars peep through them at the earth, unwilling, like stars of more earthly origin, to be completely hidden from view. Perhaps the most exquisite shape they take is that known as the 'corona', which is formed when, owing to laws of perspective, a wreath of parallel rays appears to converge on a central point. The rays then form gigantic outspread skirts, which, as though they clothed some invisible heavenly ballet-dancer, rock to and fro, or whirl about as if the dancer were inspired by a frenzied storm of emotion. These draperies may be of any or all of the characteristic polar-light colours, green, red, violet, and blue, and they are often flecked with curious red spots which have not yet been explained in any way.

Another type of drapery consists merely of a milky sheen, which has the characteristic of absorbing short radio-waves to such an extent that if such a curtain appears in the sky between transmitter and receiver, no matter with what persistence the transmitter sends out messages not one of them will penetrate that gossamer film and reach the receiver on its farther side.

The diffused light into which a display of rays usually fades may make a separate appearance in the form of clouds, white as sunlit snow, yet insubstantial as gleaming ghosts, or in the form of a gauzy veil extending over the whole sky. It may appear in throbbing or pulsating patches of light, or it may assume some grotesque shape which appears and disappears at regular intervals without altering its filmy outline.

It is quite evident that nature is devoid of vanity and performs her loveliest frolics where there are none to applaud, for it is in the uninhabited arctic regions that Polar Lights are at their brightest. In those latitudes they gleam with the muted brilliance of full moonlight, but farther south they pale, and their brightness is to that of moonlight what moonlight is to the light of day, a cold ghost of brightness that gives back a remembered light.

In the northern hemisphere the region in which Polar Lights make their most frequent appearance is well defined, and consists of an irregular circle, known as the Polar Light Girdle, which has the magnetic pole as its centre. It is probable that a similar region surrounds the south magnetic pole, but up to the present information on the subject is meagre. Within latitude 60° over the north Atlantic and North America, and within latitude 70° off the coast of Siberia, the lights can be seen on an average about a hundred times a year. Magnetic storms, however, have a great influence not only on their frequency but also on their geographical distribution, and during times of magnetic disturbances the Polar Light Girdle approaches the tropics. In 1870 Polar Lights were seen in Egypt and in India; on September 25th, 1909, in Australia and Singapore (latitude 1° N.) and in 1921 in Samoa (latitude 14° S.).

A certain number of photographs of Polar Lights were secured as early as 1892. In 1909 Carl Størmer, realizing the importance of photography in carrying on research in this subject, set to work to improve the method employed, and was so successful that in 1910 he began to make a collection of photographs by means of which he was enabled to determine at what height above the earth Polar Lights are wont to appear. In order to make this calculation two or more simultaneous photographs are taken at different stations connected for the purpose by telephone; these photographs are carefully measured, the position and length of the line between the stations is taken into account, and the position of the rays in relation to the stars.

According to Størmer's records the lowest position in which the rays of Northern Lights have been observed is 53 miles above the earth's surface. Observers have, however, stated with some confidence that they have seen rays which actually reached down to the earth. If this information is accurate it implies that the rays are capable of penetrating completely through the earth's atmosphere. But a fact of such importance cannot be accepted until it rests upon unimpeachable evidence, and we are compelled to admit that we cannot always believe the evidence of our own eyes, and perhaps even a little less often are we able to place implicit confidence in the visual evidence of others.

The highest position recorded photographically, which is, of course, the position of the upper and not the lower extremity of a ray, is 625 miles above the earth. But the average height of rays is not, as might be imagined, about midway between the two quoted. Rays have a habit of appearing at certain very definite distances above the earth, and two distances which are recorded with remarkable frequency are those of 62½ miles and 66 miles. These persistently recurring heights suggest a rhythmic, or wave-like motion, and one theory that has been advanced to account for it is that it is due to something in the nature of an ebb and flow in the Upper Atmosphere, which causes the lower extremity of a ray to rest, now on the summit, now in the trough of a wave. This theory has encountered a great deal of opposition, and has not as yet been proved; but whether it is correct or not, it emphasizes the fact that the problem of the height of Polar Lights is not aroused by mere curiosity. It is a problem that is bound up with that of the nature of the Upper Atmosphere, and information which may at first appear relevant to the one subject only may eventually throw light on the other.

The measurements given above are obtained from some thousands of photographs taken and measured by Størmer and his colleagues over a period of more than twenty years. During a single night, that of March 22nd to 23rd, 1920, no less than seven observation stations were at work, and over six hundred photographs were secured. Scientific research is, no doubt, an arduous pursuit, but during the night of a northern spring, illuminated by Northern Lights and the light of the stars, we can well imagine science wedded to poetry, and it is easy to believe that their offspring will eventually be truth.

It was in studying the results of this particular night's work that Størmer noticed that rays photographed just after sunset and just before sunrise were higher in the atmosphere than those photographed during the intervening period. The fact puzzled him, and he began to seek the reason which he believed to be lurking behind it, but it was not until six years later that he lighted on the clue that led to its discovery. On the evening of September 8th, 1926, he observed from his station near Oslo an unusual display of Polar Lights hanging high in the west over the Shetland Islands in the form of a curtain of rays of a strange violet and grey-violet colour. It then occurred to him that, although the sun had already set, these rays, about 300 miles above the earth, were not within the limit of the earth's shadow, but must be in the sun-drenched atmosphere above. Up to this time photographs had been measured to determine the position of the rays in relation to the earth's surface; it was not a difficult matter to measure them again and ascertain their position in relation to the earth's shadow. Størmer turned back to the photographs taken in 1920, in which he had noticed that the rays observed just after sunset and just before sunrise were unusually high, and discovered that the rays in both cases occurred in the region still affected by solar radiation. These, and measurements made on many other photographs, pointed to the conclusion that the rays of Polar Lights must be divided into two distinct classes, those which occur in regions immediately affected by solar radiation, and those in which immediate solar radiation, that is to say pure wave radiation, is intercepted by the earth. The former occur only at great heights, usually between 200 and 600 miles above the earth; the displays are extensive, stretching sometimes for over 1000 miles across the sky; and the rays are extremely long, the lower end often hovering on the very edge of the earth's shadow. The latter, which, when they form part of a simultaneous display, are usually separated from the former by a considerable distance of dark sky, rarely reach as high as 200 miles, and the rays are comparatively short. All these facts must be taken into consideration in any theory that attempts to explain the origin of Polar Lights.

It is impossible to say what line of research will eventually reveal this secret. A few years ago it almost seemed as though the spectrum of Polar Lights had led to its solution, and although on this occasion it proved but a will-o'-the-wisp clue there is reason to believe that it will lead in the right direction eventually; and in the meantime it has made its contribution to our knowledge of the composition of the Upper Atmosphere.

It has been pointed out in an earlier chapter that white light may be split up and spread out so that its constituent parts are seen in the form of a rainbow-coloured band, or spectrum. When the spectrum is produced by synthetic white light it consists of colours only, but when it is produced by the light of the sun, or of the moon, or of a star, it consists also of lines, superimposed upon the colours. These have been named Fraunhofer lines, after their discoverer. In the spectrum of sunlight there are many thousands of them, and it has been proved that they indicate the presence of certain elements in the source of light, most of which have been identified by means of laboratory experiments.

When a solid body is heated until it becomes incandescent the spectrum of the light it gives out consists simply of a band of colours. It has been discovered, however, that when the same solid body is heated until part of it is vaporized and the core is surrounded by gas which is cooler than that part of the body which has retained its solidity, then the spectrum consists not only of colours but also of lines; and that when the body is still further heated until it is completely gaseous the spectrum consists, not of dark lines upon a coloured band, but of a series of bright lines each standing by itself. The position of these lines depends on the elements which compose the body which has been heated, and their position remains the same whether the element they represent exists in a heavenly body or in the laboratory. If, for instance, iron is heated until it becomes gaseous, its spectrum will exhibit a certain series of bright lines; these lines appear also in the spectrum of sunlight, the only difference being that in the first they are bright, and in the second they appear dark owing to the brilliance of the light behind them.

It would not be possible, of course, to compare different spectra in this way with any accuracy except by means of photographs, and it is by means of spectral photography that the various elements in the sun and moon have been identified, and in the same way that much of our knowledge of the stars has been gained. It is easy to see the importance of this line of research in solving the problem of the composition of the Upper Atmosphere, for, when the height of the Polar Lights is known and the spectrum has been analysed, the nature of the atoms present at that height can be discovered.

The chief difficulty encountered in photographing spectra of Polar Lights is the weakness of the light itself, and this difficulty has to be overcome by means of long exposures; but Polar Lights are erratic and evanescent and do not always remain for the exposures to be completed, and it has not as yet been possible to measure and identify all the lines. Vegard, who has done distinguished work in this connection, has already succeeded in measuring thirty spectral lines. Among these he discovers no traces of the lighter gases, helium and hydrogen, and it seems possible, judging from the somewhat insufficient data available, that these particular light gases do not exist at all at any considerable height in the atmosphere. There seems little doubt, on the other hand, that nitrogen is present in the regions where Polar Lights manifest themselves. These facts go a long way towards disproving the theory mentioned previously, that the gases of which the atmosphere is composed distribute themselves according to their molecular weight.

There is a distinct difference between the spectra of Polar Lights that appear in the region affected by immediate solar radiation, and that of those in the region that lies within the earth's shadow, and in the former the famous green line, which has aroused so much controversy, is less in evidence than in the latter. This green line—its wave-length, 5577A°, is easy to remember—which is considered characteristic of the spectrum of Polar Lights, though it must be admitted that it is not visible in every example, has puzzled many investigators in their attempts to identify it. Vegard produced a similar spectrum in the laboratory by bombarding frozen nitrogen with cathode rays, and drew the somewhat premature conclusion that Polar Lights were caused by the impact, in the Upper Atmosphere, of fast electrons emitted by the sun with frozen nitrogen. The green lines, however, though very much alike, were not precisely identical, and a few years later it was discovered by MacLennan that a green line even more in agreement with that of the polar-light spectrum could be obtained in certain conditions from radiation emitted by a mixture of helium and oxygen. Still more recently it was discovered that the light emitted by the night sky in California produced a spectrum containing a similar green line, and since Polar Lights are only very rarely visible in California it seems reasonable to draw the conclusion that this famous green line is characteristic, not of Polar Lights, but simply of the light of the night sky, which would, of course, be inherent in any spectrum photographed at night.

This controversy over the green line confronts us with the question which has probably been in our thoughts from the beginning of the chapter, namely: What is it that causes the Polar Lights? It is a question that is not readily answered. In the first place we must go back again to the atom. Remembering that the origin of radiation is a momentary alteration in the orbit of an encircling electron by means of which energy is lost to the atom, we realize at once that the atom must be primarily responsible for this beautiful pageant of strange lights. We might be excused for mistaking effect for cause and remarking that it is no wonder that the atom is excited, but we get nowhere when we put the cart before the horse, and the problem cannot be solved by juggling tricks. It is, in fact, a twofold problem. What is the nature of the atom which emits the radiation?

and what is the agent responsible for causing the atom to emit radiation?

With regard to the first question it seems likely that spectral photography will lead considerably further towards an answer than it has done at present, but before any conclusion can be reached it will be necessary to know more than is known at present both of the temperature, and also of the physical composition of the atmosphere at the height concerned, for in different circumstances atoms, not unlike humans, behave in different ways. There are at least 90 types of atom to choose from, and although many of these can be ruled out of account altogether there is still a considerable range of choice left.

When we come to enquire into possibilities as to the agency which causes the atom to emit radiation the choice is more circumscribed. Taking into account the facts which have already been touched upon in this chapter we may be justified in assuming that this agent has its origin in the sun, and consists of some form of radiation which is affected by the earth's magnetic field. There are only four definite groups of solar radiation. The first includes visible light-rays, and ultra-violet rays, which take, on an average, about 8 minutes to travel from the sun to the earth; but as their course is not affected by the earth's magnetic field they need not be considered any further in this connection. The second group includes X-rays, and solar gamma rays. These also travel with the speed of light, and as they are pure rays are also unaffected by a magnetic field. The third group consists of ultra-gamma, or cosmic rays, and as it has not been suggested that they have any connection with Polar Lights the discussion of their nature may be conveniently postponed until the next chapter.

There remains then only the fourth group, which consists of solar corpuscular rays, and in this group we may expect to find the agent responsible for the creation of Polar Lights. It includes four distinct types of material particles:

1. Electrons, or fast cathode rays.
2. Positive ions, or ionized atoms.
3. Neutrons.
4. Positrons.

Of these, neutrons can be ignored, for since their charge is zero their course must be independent of any magnetic field. Too little is known of the positron to allow us to take it into account at this stage, so there are left for our consideration the first two types only, electrons and positive ions. The speed of electrons and positive ions varies considerably, but there are plausible grounds for assuming that they have an average speed of approximately 700 miles per second, and therefore if they were to travel in a straight line they would take about 36 hours to travel from the sun to the earth. Their course, however, must be affected both by the magnetic field of the sun, and also by that of the earth, and consequently they must leave the sun in a spiral direction, and again describe a spiral when they come within the influence of the earth's magnetic field. This curve in their course makes it somewhat difficult to calculate the time they take on their journey.

Birkeland, who maintains the theory that Polar Lights are created by the impact of some type of solar corpuscular radiation with layers of the Upper Atmosphere, under the influence of the earth's magnetic field, has conducted some very interesting experiments with spheres varnished with barium platinocyanide, a paint which fluoresces, that is to say emits a temporary radiation, when it encounters cathode rays. When a sphere of this kind, placed in a vacuum, is magnetized by a strong current of electricity and bombarded with cathode rays, a luminous ring is formed round the equator. As the current is increased the ring widens, and, when it is made still more intense, in addition to the equatorial light two spirally shaped girdles of light form in the neighbourhood of the poles. If this miniature earth were increased to its proper size, and the position of these rings of light was calculated proportionately, then the girdle round the equator would be about 600,000 miles above the earth, too distant to be visible from the earth's surface, and the rings round the poles would occupy the zones in which Polar Lights are wont to manifest themselves.

Størmer has worked out mathematically the probable curve of corpuscular radiation as affected by the two magnetic fields of earth and sun, and his calculations support the evidence of Birkeland's model earth. This curving of the path of corpuscular radiation accounts for the great ring, empty of corpuscular rays, which according to his calculations encircles the earth, and it is outside this ring, within a zone surrounding each pole, that corpuscular rays stream towards the earth; and their impact with the atoms of the Upper Atmosphere may be the cause of the radiation which we recognize as Polar Lights.

Størmer himself does not consider this theory of their origin complete or final, and he is still working at the problem. Every paragraph he writes on the subject evinces eagerness and enthusiasm, and it is easy to see that he is still in thrall to this fascinating mystery. And indeed what more alluring subject of research can be imagined than these lights which gleam in the upper fringes of the air, tethered so lightly to earth, yet incapable of existence in space, the last visible outpost of the Upper Atmosphere?

Chapter Eight

Cosmic Rays

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If a foreign traveller were to arrive in this country speaking some language which had little or no resemblance to any known tongue, and wearing strange clothes fashioned from some material hitherto unheard of, we should all be very anxious to find out where he came from, and what kind of country it might be. If, in addition, the traveller possessed, let us suppose, the faculty of seeing through substances such as wood or stone, or the capacity of reading our unspoken thoughts, his arrival would undoubtedly be announced in the press in inch-high headlines, and columns would be devoted to speculations as to his origin.

It may as well be confessed at once that so far as we know no such human traveller has recently arrived. If we have been fortunate we have, however, already succeeded in showing that man is not the only interesting voyager; there are others that go farther afield—or may we coin a new word and say farther aspace?—and if their log-books are sometimes written in a language difficult to decipher, and liable to error in translation, we have only to read a small selection of human travel-diaries to realize that they also are liable to some inaccuracy. We must be prepared for 'travellers' tales' from all types of travellers, it seems, and the scientific voyages we have been describing have at least some advantages in the matter of speed and distance.

The story of Cosmic Rays is, in many ways, analogous to the story of the mysterious traveller we have pictured. Like the atom these rays have had to wait some millions of years for their publicity, but it has come at last; and although we have to admit that their arrival has not been announced on the newspaper placards, but only in a modest paragraph here and there, we can console ourselves with the reflection that, after all, a heavenly star is less blinding than a magnesium flare. Their discovery, 'epoch-making' though it may be, was not made with startling suddenness but was a quiet affair occupying a number of years.

It was due in the beginning to observations made in connection with a little instrument known as a gold-leaf electroscope. This instrument consists of two gold leaves which normally hang close together, but when charged in the same way repel each other. As early as 1900 it was noticed that when this instrument was charged and left to itself, no matter how perfect the insulation might be, the charge was gradually lost; in other words the insulation did not remain perfect, and a medium, originally non-conductive, became in some way converted into a conductive medium through which the charge escaped. It will be remembered that this is precisely what happens in the case of the ionization of a gas, and that such ionization is effected by rays of a very short wave-length, ultra-violet rays, or X-rays, or the gamma rays of radium, which detach the electrons from the atom, and so change it from a neutral particle into negative and positive charges —electrons and ions. It was assumed, then, that the gold-leaf electroscope lost its charge on account of ionization.

Experiments were made by taking the precautions necessary to exclude all known forms of ionizing radiation. The electroscope was enclosed within opaque walls which effectively cut off ultra-violet radiation; it was covered with sheets of metal which absorbed X-rays or gamma rays coming from without. Ionization still continued, and since it could not, in the circumstances, be attributed to any known form of radiation, it must have been caused by some radiation which had not hitherto been detected in any other way. The electroscope was then enclosed in sheets of lead, and it was observed that the charge was lost more slowly as the thickness of the lead was increased, but it was nevertheless lost; therefore the radiation must have been absorbed to some extent, but not altogether, by the lead. The effect of the unknown radiation was incontestable, but its source was a complete mystery. Here then was the strange traveller, with his peculiar characteristics. Where had he come from?

The first suggestion made was that this radiation consisted of gamma rays emitted by radioactive substances in the earth's crust. It was not difficult to put this theory to the test, for if it were correct the effect of the radiation would diminish with distance from the earth's surface, and this effect could be measured by its ionizing power. Measurements were first made on the top of the Eiffel Tower in Paris, and these measurements showed a slight decrease in ionization. When, however, measurements were made at greater heights by means of balloon ascents by Gockel, in Switzerland, and Hess in Austria, the results were entirely different.

The ionizing power did not decrease; on the contrary, after a slight decrease at first it actually increased with distance from the earth, which proved conclusively that its origin must be discovered elsewhere. In 1906 Richardson (of London) had suggested the existence of some highly penetrating type of radiation which had its origin neither on nor in the earth, and the observations made by Gockel and Hess between 1909 and 1913 gave solid support to his suggestion. These rays of unknown origin, which can shatter electrons from the conservative atom even when it is protected by several feet of lead, have become known to us as Cosmic Rays.

There is nothing unusual in the fact that the presence of Cosmic Rays can be detected only by the effect they produce. When we see a chimney blown down we all realize that there must be something of a wind blowing—unless of course the effect was due to an earthquake—and even when we see aspens aquiver we are ready to admit that there is a little breeze about. From the scientific point of view ionization is a scarcely less evident effect, and its extent can be tested and measured with considerable accuracy. After that comes the problem of deciding between rival causes, as, in the case of the chimney, between wind and earthquake.

There are three different types of instruments that are used in measuring the ionizing power of Cosmic Rays. The first of these consists of an ionization-chamber used in conjunction with a string electrometer. The ionization-chamber is a hollow brass cylinder containing a rod of the same material, supported by a second rod which is insulated from contact with the chamber by some such material as amber, and is connected with the electrometer outside. The cylinder itself is connected to one end of a battery of electric cells, the other end of which is connected to the earth. When X-rays are used for purposes of ionization they are admitted into the chamber through a thin aluminium window, but for Cosmic Rays the window is unnecessary as the rays are able to penetrate the walls of the cylinder itself and shatter atoms within, transforming them into free electrons and ions, which flow either to the walls of the chamber or to the insulated brass rod, according to whether the chamber is at a negative or positive potential. The electrometer to which this chamber is connected consists of a very fine thread placed between two plates which are separated by a small distance and oppositely charged. When there are no ions within the ionization-chamber, and therefore no charge is conveyed to the electrometer, the position of the string is at the zero of a scale which is contained by the instrument and illuminated by an external mirror; but as soon as a charge accumulates on the string it begins to move along the scale. Its position, and therefore the strength of the charge, can either be read through a microscope, or photographed at regular intervals by a camera, and in this way record is made of the amount of ionization that is proceeding within the chamber.

The second instrument that is used to measure the intensity of Cosmic Rays is known as the Rutherford-Geiger counter. The principle is the same as that of the ordinary ionization-chamber, but the effect is much magnified by cumulative ionization. By connecting the cylinder to a large battery of small accumulators, of which the other end is earthed, it is kept at a high potential of anything from 1000 to 2000 volts. If this is a negative potential an electron entering the chamber will be strongly attracted to the point of the insulated needle, which takes the place of the brass rod used in the instrument previously described. The attraction will cause such an acceleration of the speed of the electron that it will shatter the atoms that it encounters on its headlong journey, and so produce more electrons, which, if they have far enough to travel before they also reach the point, will in their turn shatter more atoms, and produce still more electrons; this avalanche-like effect continues until the electrons reach the needle, and the charge, which is by now appreciable, is recorded by the electrometer. If the chamber is positively charged a similar effect will be produced, not by an electron but by an alpha particle, or any other positive ion. In order to appreciate the significance of the advance made by the invention of this instrument it must be remembered that the smallest current measurable by the most refined electrical instrument is of the order of 10^{-15} ampères, that is to say that about 10,000 electrons must be received in the instrument per second, whilst by the method of accumulation used in the Rutherford-Geiger counter the effect of the entry into the chamber of each individual electrified particle is so much increased that it is possible to count each one. The effect can, in fact, be turned into sound by amplifying the current of ions and connecting it to a loud speaker instead of to an electrometer. In that case the entry of the charged particle is made with a noise quite inappropriate to its size, loud enough, it may be, to carry conviction to the type of mind that is impervious to quiet statement but susceptible to oratory.

This type of counter has again been improved upon by substituting for the needle a wire which runs from one ebonite cork of the cylinder to the other, the absence of the point giving more consistency to the records. This improved instrument is known as the Geiger-Müller counter, and is the one most in use at the present time.

The third type of instrument which is employed in the investigation of Cosmic Rays makes use of a principle altogether different from that of the other two, and is based on the fact that if a gas is allowed to expand suddenly its temperature falls. It is an instrument devised by C. T. R. Wilson of

Cambridge, and is known as the Wilson cloud-chamber. It detects ionization, not by means of the electric current produced, but visually, by means of a cloud-track formed along the path of the charged particle. This is the nearest approach we can make to seeing the charged particle, and although the particle itself is not, strictly speaking, visible, it is at least as visible as is the wind when we see it pass over the sea in dark patches of ruffled water.

When air which is saturated with water vapour is caused to expand it immediately cools, and if dust, or any other particle which can act as a nucleus on which it can collect, is present, this process of cooling causes some of the moisture to condense and form a minute cloud. The particles are invisible if no moisture reveals their presence, and the moisture remains invisible if it finds no particle on which to condense. If ions, which form convenient nuclei for condensation, are produced in the cloud-chamber just after the gas which it contains has been made to expand, moisture condenses upon, and exposes them. A single charged particle, the offspring, let us suppose, of a collision between a Cosmic Ray and an atom, passing through the gas will of course shatter the atoms it encounters in its passage, and so produce more ions, or charged particles, each of which will form a centre around which moisture will condense. In this way the trail of the original charged particle may actually become visible for a moment as a thin white thread, and can be photographed by means of a high-speed camera.

It is easy to see that the cloud-chamber must be a most fruitful source of information, not only about the ionizing capacity of Cosmic Rays, but also about the electrified particle itself, for by studying the length and direction of its tracks much may be learnt of its speed and nature. It was, in fact, by means of the cloud-chamber that Chadwick and his colleagues discovered the existence of the neutron, which consists of a proton and an electron in such close union that some of the mass is lost, and the atomic weight of the combination is therefore less than the combined atomic weight of one proton and one electron. As the neutron contains one positive and one negative charge one neutralizes the other, and its net charge is zero.

Still more recently the existence of the positron, or positive electron, appears to have been established both by Anderson of America, and Blackett and Occhialini of Cambridge. The positron is the positive charge detached from the proton, and can only exist at very high velocities. This discovery would indicate that atoms are built up, not only, as has hitherto been believed, of protons and electrons, but also, possibly, of positrons, electrons, and 'dead matter', i.e., the proton minus the positron.

This, however, is by the way, and merely serves to illustrate the wide usefulness of such instruments as have been described. Considerable space has been given to these descriptions, partly for the benefit of the sceptic, who, when confronted with an established scientific fact, enquires 'How can they possibly know?' and partly, too, for the benefit of those who are interested in the processes by which scientific knowledge is gained, the foundation upon which the visible structure rests. Scientific instruments can hardly be expected to be as simple as a child's toys, but some indication of the methods used makes, not only for confidence in the results gained, but also for patience with the difficulties encountered on the way.

The most important question that has arisen in connection with Cosmic Rays is 'Where do they come from?' and it is doubtful whether this question has yet received its final answer. The suggestion that their origin was in the earth's crust having been summarily disposed of, the theory advanced was that they came from the sun. This second theory could also be put to the proof without difficulty, for their intensity, or effectiveness, could be tested by day and night, and the results compared. These results did not favour the sun as origin, for the intensity was approximately the same both by day and night, and even during eclipses. It is, however, not quite as easy to dispose of this theory as it was of the previous one, for it is conceivable that certain high-speed particles in striking the outer atmosphere of the earth produce Cosmic Rays as a secondary radiation, and in that case the sun might still be regarded as the primary source.

In order to throw more light on this question of origin an immense amount of research has been carried on with the object of discovering the wave-length of the radiation, and the variations in its intensity both with height and depth, and with geographical distribution.

Regener of Stuttgart has done extensive research both in determining to what extent Cosmic Rays lose their effectiveness in traversing water, and also to what extent this effectiveness increases with height. Millikan, in 1925, had carried out a similar experiment by lowering an automatically recording electroscope into a snow-fed lake at a high altitude. This experiment illustrates one of the difficulties encountered in research work, for had the water in which the experiment was made been derived otherwise than directly from snow it might have contained radio-active substances which would have emitted gamma rays, and these rays would have had an ionizing effect indistinguishable from that produced by Cosmic Rays, and so would have falsified the records.

Regener's experiments were carried out in Lake Constance by means of an instrument that made a photographic record of the position of the thread of the electrometer every 4 hours. Both he and Millikan found that the ionizing effect decreased with depth, the string of the electrometer making smaller advances along the scale as the depth increased, so that the photographic records have the appearance of a series of hair-combs, with smaller and smaller spaces between the teeth, until finally they become a continuous blur, each line overlapping the previous one. But even at the lowest depth at which records were made, a depth of over 800 feet, the line of the string continued to advance by almost imperceptible degrees; and this proved that ionization, although very small, still persisted, and that at least some of the Cosmic Rays were so powerful that, beneath a mass of water which, if it were earth and stood upon the level plain, would stand almost as high as the Malvern Hills, they were still strong enough to part the tenacious electron from the atom.

In determining the intensity of Cosmic Rays at different heights Regener made use of the specially designed balloons described in an earlier chapter. These balloons carried an ionization-chamber and electrometer to a height of 17½ miles, and during the various ascents photographic records were made automatically at regular intervals of 4 minutes. In this way he was able to collect an enormous amount of data which enabled him to plot the curve of intensity against height with great accuracy.

Piccard, whose ascents with a similar objective have also been described, connected his ionization-chamber with an amplifier, so that as he ascended into the stratosphere he was able to listen to the sound produced by the ionization effected by the Cosmic Rays. Hence the remark in his report that Cosmic Rays were 'rattling down on his gondola'.

In March, 1933, Regener published a detailed account of his results, which agree very well with those obtained both by Piccard and by Kolhörster, who is one of the pioneer workers on Cosmic Rays, and was among the earliest to make records of their varying intensity in different parts of the world. The intensity of Cosmic Rays appears to increase in an exponential manner up to a height of about 15 miles, after which point it increases so slowly that it can almost be said to be stationary. In the uppermost reaches of the atmosphere about 333 pairs of ions per cubic centimetre are formed, that is to say 150 times more than at sea-level. In this connection it may be mentioned that Benndorf has estimated that at a height of about 60 miles the electric conductivity of the air must be 10,000,000,000 times greater than at the earth's surface, owing to the action of Cosmic Rays alone, and that at this height it conducts just as well as does the dry ground. Regener has calculated that the amount of energy that reaches the earth in the form of Cosmic Rays is approximately equal to that of the light and heat of all the stars, excluding, of course, that of the sun, moon and planets.

In comparing the absorbing power of the atmosphere with regard to Cosmic Rays with that of water we notice that the absorbing power of the whole atmosphere corresponds to that of about 10 metres of water, the height equivalent to the barometric pressure of air as expressed in the height of a water column.

The most recent, and also the most extensive, records of the geographical distribution of Cosmic Rays have been made by eight co-ordinated expeditions organized from the Universities of Chicago and Denver during the years 1932 and 1933. These expeditions collected data from stations distributed all over the world, not only at sea-level, but also at as great a variety of altitudes as possible, and their headquarters were situated as far north as Spitzbergen and as far south as New Zealand. Up to the time of the publication of these results there was some doubt as to whether cosmic radiation was in any way affected by the earth's magnetic field, but these carefully assembled records leave very little doubt that it is, for the intensity is considerably greater in high latitudes than it is near the equator, and follows the geomagnetic, rather than the geographic or magnetic latitude. This result implies that the radiation must consist in part at least, though not necessarily altogether, of particles which are subject to the influence of a magnetic field.

Very interesting experiments of a totally different nature have been carried out by Kunze of Rostock, who has worked on the assumption that Cosmic Rays consist of a mixture of pure rays and high-speed particles, and has concerned himself with the investigation of the tracks of charged particles observed in the Wilson cloud-chamber when it has been placed in a very intense magnetic field. When a charged particle passes through a uniform magnetic field which is in a direction perpendicular to its own its track is bent in accordance with its speed, and is deflected either to the right or to the left according to whether its charge is negative or positive; and, if the mass and charge of the particle are known, its velocity can be calculated from the extent to which its course is curved. In the case of a charged particle moving with a very high speed, however, the magnetic field must be of very great intensity to cause any appreciable deflection, an intensity far greater than can be supplied by any ordinary scientific institution.

Through the courtesy of the authorities responsible Kunze obtained permission to make use of the electrical supply of the city of Rostock during the very early hours of the morning, when, for obvious reasons, little was required by the inhabitants for domestic purposes. Two rectifiers were used, which gave in parallel 500 volts and 1000 ampères; this current was sent through a water-cooled coil, of which the weight of the copper alone was 1100 kilogrammes, and which had a resistance of half an ohm at ordinary temperatures.

The magnetic field around such a large dipole is extremely powerful even at a considerable distance, and during the few moments that the current was in use it had some disconcerting effects. Although the neighbourhood of the magnetic field was carefully searched beforehand for any odd pieces of iron, something was always liable to be overlooked, and when the current was switched on stray nails would come hissing through the air as if shot from a gun, metal covers were ripped from instruments, camera shutters jammed, and concealed pins were indiscreetly torn from clothing. In spite of these minor embarrassments photographic records were made of the tracks of 90 charged particles. Of these rather more were of positively charged ultra-particles than of negatively charged ions. The greatest measured particle had a velocity of 2,660,000,000 volts, and two others that could not be measured had velocities of 3,500,000,000 and 9,200,000,000 volts respectively. In order to appreciate the magnitude of these velocities we must remember that the speed of an electron of, let us say, 100 volts is the speed it acquires in passing from a plate at earth potential to another at a potential of 100 volts, and if we wish to calculate it in miles per second we must multiply the square root of volts by 375. The figure obtained for the higher speeds, however, is misleading, for according to Einstein's Theory no particle can move with a speed greater than that of light. This fact is connected with another that has been definitely established experimentally, namely that as the velocity of the moving particle increases there is an apparent increase in its mass. The speed of these particles must be considered, therefore, as actually a very little less than 186,000 miles per second. If some of the constituents of cosmic radiation actually strike the earth at this velocity it is not difficult to understand that they are able to penetrate a great depth of water, and even a considerable thickness of metal.

On the results of these various types of research, which have been indicated rather than described, several theories of the origin of Cosmic Rays have been built up, of which the most important are probably the two contrasting, but not necessarily conflicting ones advanced by Regener and by Millikan, with which the names of Jeans and Cameron are also associated. There is also a third theory which has been very recently proposed by a Swedish physicist, Hannes Alfven, which is deserving of attention.

Alfven bases his theory on the fact that if a light body collides with a heavier body the lighter body generally gains energy at the expense of the heavier body, and so tends to gather more speed at every encounter. When an atom is travelling through space it will probably meet clusters of other atoms in the form of a giant molecule; it does not necessarily collide with the cluster, but in passing near to it it will, on account of the electrical forces contained in both bodies, gather energy, and after numerous encounters of this kind will accumulate enormous speed, which might amount to as much as 1,000,000,000 electron volts, and so account for the puzzling factor of the extraordinary velocity of Cosmic Rays.

Another suggestion which has been made since the discovery of the neutron is that some constituents of Cosmic Rays might consist of streams of very fast neutrons. Since a neutron is of an extremely small size and is surrounded by an ex-

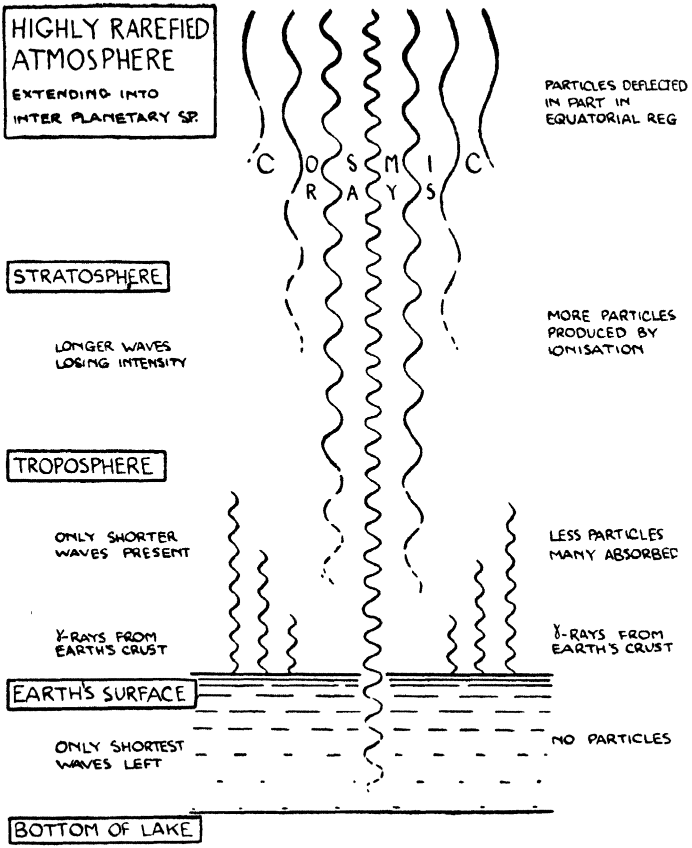

DIAGRAM SHOWING THE GRADUAL ABSORPTION OF COSMIC RAYS IN THE ATMOSPHERE AND IN WATER tremely small field of force, it can penetrate atoms of matter without difficulty. This theory would account for the penetrating power of Cosmic Rays, but on the other hand it would upset the conclusions drawn by Kunze from his deflection experiments, for the path of neutrons could not be affected by a magnetic field. Nor would it agree with the findings of Compton as to the distribution of intensity in relation to geomagnetic latitudes. Were this theory correct those constituents of Cosmic Rays which consist of neutrons would have to be considered as completely different from those investigated by Compton and Kunze.

There is no doubt that the most interesting theories of all, and in many ways the most acceptable, are those advanced by Regener and by Millikan, for they open up a field of speculation no less extensive than that of the creation and annihilation of matter in outer space, wherein might be found the secret of the beginning and end of all things.

From the analysis of the results of his extensive experiments Regener draws the conclusion that cosmic radiation consists of five groups of rays of varying hardness—that is to say of varying power of penetration, those of the shortest wave-length being the most penetrating. He is inclined to think that all five groups are true wave radiation, and not streams of electrified particles, as postulated by Kunze, and that the two hardest components, which he calls H2 and H1, are produced by the collision of a fast proton with a helium atom, resulting in the annihilation of both.

Einstein has shown that one of the results of the Special Theory of Relativity which he established in 1906 is that there is a definite equivalence between mass and energy, the equivalence being that energy is equal to mass multiplied by the square of the velocity of light, expressed in the appropriate units $(E=Mxc^2)$. So great a multiplication factor implies that the amount of energy corresponding to even an extremely small mass like that of a proton or an electron is enormous. By making use of Einstein's relation and expressing the energy as a quantum it is easily found that the wave-length of the corresponding quantum of radiation is $\lambda=0.00013$A°-units, i.e. $1.3.1\bar{0}^{12}$ centimetres, which is equivalent to 950,000,000 volts. Regener gives the value for the transformation of the mass of a helium atom and a proton into energy as 3,800,000,000 volts and 900,000,000 volts respectively. This latter figure corresponds so nearly with the one given above that it certainly lends support to Regener's theory that it is, in actual fact, the energy produced by the annihilation of the mass of a proton. It is, however, too small to correspond to the figure estimated by Millikan from measurements of the absorption coefficient of the rays in water, and so, although Regener's theory appears to hold good for the harder Cosmic Rays, it can hardly apply to all cosmic radiation.

For the softer, or less penetrating groups of Cosmic Rays the theory advanced by Millikan and Cameron in 1928 has more to commend it. They suggest that cosmic radiation owes its origin, not to the annihilation of matter, but, on the contrary, to its creation. They base their assumption on the fact that there is a certain loss of mass, known as mass defect, when protons are brought into close spatial relationship. For instance, although the helium nucleus (or alpha particle) actually consists of 4 protons and 2 electrons held close together, its mass is less than that of 4 protons taken separately and added to that of 2 electrons. Therefore when a helium nucleus is built up from its constituent parts there is an escape of mass, which, if it is converted into energy, will have a wave-length corresponding very nearly with the wave-length obtained by Millikan for Cosmic Rays.

The theory of Millikan and Cameron is that cosmic radiation originates with the actual formation in space of the nuclei of oxygen, nitrogen, and silicon, and with the consequent conversion of mass into energy, whilst Jeans has advanced still further on the lines he suggested in 1925, and which Regener's results support, and seeks to prove that its origin is to be found in the simultaneous destruction not only of one proton and one electron, but of several protons and electrons, and even of a complete helium atom.

If the suggestion is accepted that the harder groups of Cosmic Rays have their origin in the destruction of matter, and the softer groups in the creation of matter, since the intensity of the softer components is much greater than that of the harder components it would seem that the synthetic process of building up helium nuclei occurs much more often than the process of their annihilation.

It may quite well be that these theories are both correct, and that these two processes are continually going on in outer space, resulting in the production not of one only, but of various types of radiation. Throughout interstellar space Cosmic Rays appear to have a finite density, and this is a determining factor in cosmological theories, such as the theory for giving an approximate value to the periods of Einstein's pulsating universe.

And here, beyond the fringe of the Upper Atmosphere, and looking out over the vast prospect of the universe, it is fitting that this voyage of exploration should come to an end. It started in a homely way with a parachute and a leap from a tree. We can hardly say that the beginning led anywhere, it was a mere assertion of man's aspiration towards independence of the earth. The first balloon was a triumph of achievement, and before manned balloons were outpaced the troposphere had been traversed, the tropopause discovered, and Piccard and Kipfer had ventured into the bright serenity of the stratosphere. To reach the limit of this region and reveal the existence of the ozonosphere entirely different explorers were necessary: sound-waves, dispatched from and returning to the earth; ultra-violet rays, starting from the sun and penetrating our atmosphere; meteorites pursuing their orbits in the solar system.

The ionosphere was added to our map almost entirely as the result of the journeys of radio-waves; and long-distance echoes were fruitful in suggestion as to the course described by corpuscular radiation between sun and earth. High in the outer atmosphere beckoned the polar lights, demanding the answer to the riddle of the atomic constitution of those regions, and again corpuscular radiation from the sun must assist in finding the answer. Then came Cosmic Rays.

They have brought us face to face with the mystery of creation and disintegration, and have led us to the brink of speculation on the subject of cosmology.

Like the balloon we have been carried by our momentum beyond our rightful point of equilibrium, and before rising any higher we must descend a little. But the voyage has been long enough. We have reached our objective for the moment, and the decision has been made to go no farther. Other voyagers will follow in due course, for it is impossible to believe that reality is anything but inexhaustible.

If any of our fellow voyagers feel inclined to remark, in the words of the elder Weller, 'That's rather a sudden pull-up, ain't it?' we must answer, imitating the discretion of his son, 'Not a bit on it; she'll vish there was more, and that's the great art o' letter writin'!' and of all other writing, and particularly, we hope, of the writing of this book.

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