1. METEOROLOGY FOR SCHOOLS AND COLLEGES

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WHENEVER the country decides that the Study of Weather is a subject of national importance, and judging by the experiences of the War the time is not far distant, it will be necessary for meteorologists to arrange the various divisions of the science in some sort of order according to the stage of mental development which the student may be assumed to have reached. Hitherto British books which have Meteorology for their title have been addressed to the general public and have avoided as far as possible any assumption of preliminary technical knowledge. The authors have had to explain physical processes and other things as they went along or to assume that no explanation is necessary. A common practice has been to lay down brief statements as a sort of concrete foundation of physical principle upon which to build a superstructure of explanation. When one looks into the matter all the processes of weather turn out to be much more complicated than the early meteorologists thought them to be. For example, when you have satisfied the inquiring mind, by some form of demonstration, that air becomes colder when it is rarefied dynamically it seems quite easy to extend the idea to explain that when a current of air flows over a mountain-chain it gets rarefied by elevation, and consequently cooled, with rainfall as the result. So certain are we of the soundness of the explanation that we have given the special name of orographic rainfall to the precipitation produced in that way. But when you come to think of it, the explanation requires that the air on the windward side has to be made to flow up-hill, and no fluid which technically must be called heavy, as it is affected by gravity, even if it is as light as air, flows up-hill without protest. It prefers to go round, and will exhaust all the possibilities of doing so before submitting to be driven over. As, however, the rainfall itself shows that air does get over mountain ranges, the possibilities are obviously exhausted, but the protest is somehow or other recorded; and before we regard the explanation as complete we ought to know what form the protest takes.

Or, to take another example: there are many meteorological processes which have been disposed of by the simple statement that warm air is lighter, bulk for bulk, than cold air, and moist air than dry air, and therefore warm air or moist air will rise. So it will in the comfortable environment of a physical lecture-room, but if you are applying the principle to explain the phenomena of weather you must be prepared for the inquiries how far will it rise, why does it ever stop, and why apparently is the warm air of the Sahara or the moist air of a London fog so reluctant to betake itself to the upper regions?

According to my recollection of physical geography at school we found no difficulty in accepting these summary explanations. True or untrue, adequate or inadequate, they helped us to remember the facts which were presented to us in maps which I still regard as the most enchanting form of literature. If I wanted to show benevolence to the British schoolboy I would take care that each one of him—or perhaps, better, every other one—should have an atlas of his very own when he is about ten years old, and as he grows up always a bigger and a better atlas, but not too big for him to carry easily. The glamour of the first possession of a physical atlas is still in my memory. It showed us oceans and their depths, continents and their heights, ocean currents and ocean winds, regions of perpetual snow, volcanoes, uninhabitable deserts, rivers and their courses, heights where trees grew or beasts wandered or birds soared, isotherms of mean temperature; pressure had not then got into maps. We asked for no references; we wanted no authorities; what was on the map might be explained, but it was not to be gainsaid or doubted. After years of implicit faith in them I wonder now to myself what an isotherm of mean temperature really means, who made it, and how did he draw those lines so firmly where the foot of civilised man had never trodden; who were the travellers who found out about the snow-lines and the trees and beasts and birds, and what is the authority for those ordered currents of wind and water? Fifty years ago, why should my enjoyment of the facts be marred by questionings about the authorities for them? That I should ever have lived to go behind the figures displayed in the physical atlas of my school days and even be the means of making better ones for the schoolboys who will come after me is a stupendous thought, as I look back.

I would still not seek to disturb a schoolboy's confidence in his maps. So long as you are dealing with the facts merely as facts, if the maps represent the best facts available we need not trouble ourselves, because, fifty years hence, some officious director of a meteorological office may draw the lines and arrows somewhat differently. If we like to draw isobars crossing a range of mountains without even a tiny waggle as an expression of protest I see no objection, provided we do not afterwards quote it as evidence that no protest is made in real life. And the like is true about climatic diagrams and climatological tables. For school purposes we need not wait until that far-off time when they will be quite beyond the reproach of the most competent expert. But things are quite different as soon as we begin to deal with the physical explanation of the atmospheric processes. It then becomes of the highest importance to examine and test every fact and figure. For example, in the climatological tables appended to *The Weather Map*[1], recently published, there are figures for absolute humidity which seem to show that, on the average, in our own climate the air gains moisture from daybreak onwards and loses moisture in the night hours, whereas the opposite is the case in the climate of Helwan in Lower Egypt. Now this may be, and very likely is, a real phenomenon that is susceptible of physical explanation; any one of us could, in

[1] M.O. Publication, No. 225. H.M. Stationery Office.

fact, offer a qualitative account of the process; but if we wished to verify it by actual figures it would be necessary to remember that the figures are obtained in each case from readings of the wet and dry bulbs, that they are reduced by different hygrometric tables, and that the dry climate of Helwan presents the best opportunity on earth for exhibiting the differences between the two sets of tables. So our attitude must be different according as we regard maps, diagrams, and tables merely as the representations of the best available facts or the final and actual basis of the physical explanation of the atmospheric circulation with all its incidental phenomena.

The physical explanations which were given in my school-days are, I believe, mostly fairy tales. I call them fairy tales because they deal so simply and swiftly with situations that in ordinary nature are dreadfully complicated. I see no harm in using fairy tales as a sort of connective tissue to help young boys to keep facts in their memories. Some sort of plausible story is necessary to satisfy the question Why? which is natural, not only to young boys, but to everybody who is not disciplined to be content with the answer to How? Of course, the tales ought to have as much verisimilitude as circumstances permit. If it could be avoided, I would not risk hurting Cinderella's pretty foot by a glass slipper that was obviously chipped. The worst of the fairy tales of physical geography was, not that schoolboys used them to string facts together with, but that they were accepted without verification by grown-up meteorologists as the basis of the dynamical explanation of the facts of the atmospheric circulation[1]. We have no use for fairy tales when dealing with fully reasoned physical explanations. The sovereign rule in that case is to prove all things, distrust everything that is not strictly proved, and if the particular question requires more accurate facts than those which are available wait till you have them, and meanwhile try something else, though it may be less ambitious.

The testing of generalisations and the development of theories may well be regarded as marking the difference between the meteorology of schools and the meteorology of colleges when the time comes. Yet I do not mean that it would be well to draw a hard and fast line. The boys of the upper classes of schools are sometimes equipped with adequate knowledge for the commencement of rigorous theory; they have the necessary knowledge of the laws and principles of dynamics and physics.

At the celebration of the fiftieth anniversary of the Society I was much struck by a remark of the President, the late Dr Theodore Williams. He commended meteorology because it was so easy; it could be pursued by an intelligent gardener. The remark is true enough for that part of meteorology which consists in the compilation of trustworthy observations on an organised

[1] For example, it is customary to regard the ascent of air and consequent rainfall of the doldrums of the Atlantic as one of the controlling factors of the general circulation, but I find Professor Cleveland Abbé, writing from personal experience (*Hann Band*, p. 258), says, "The isolated rainclouds from which showers fall in the doldrums do not necessarily represent important general ascending currents. They rarely occur at night-time, and are too infrequent and too small to represent any considerable part of the immense masses of air that flow toward the equator."

plan and their representation in tables, maps, and diagrams; that part, in fact, which I have called Meteorology for Schools. But the other part, the tracing of the physical causes of observed effects, which I have called Meteorology for Colleges, is of a different character. In the course of the last year I have given a general outline of what is understood by modern meteorology in *The Weather Map*, and have found it necessary, by way of explanation, to compile an auxiliary Glossary in which are collected some of the general principles and materials for the dynamical explanations. Any one who goes through that process will realise how easy and straightforward is the path, so long as we are dealing with the collection of facts, the formation of tables, maps, and diagrams—as far, in fact, as the compilation of a weather map and the lessons to be drawn directly from the study of maps, which include the principles of forecasting by means of weather charts. All these things are quite within the range of schoolboys, not of course to initiate, but to recapitulate; and they form already, as a matter of fact, a part of the curriculum in many schools. The maps, tables, and diagrams included in *The Weather Map* are a sufficient indication of that division of the subject. But let us go a step further and consider what the equipment of a student of the physical processes must be.

That part of physical geography which deals with the shape of the earth and her rotation, night and day, and the measurement of time, the motion of the earth in her orbit and the seasons, must be familiar to him. They will involve some knowledge of geometry and trigonometry. He must know something about the composition of the atmosphere, water-vapour, vapour-pressure, saturation, condensation, evaporation, and the numerical expression of these quantities, not at all an easy subject until familiarity has made it so.

But perhaps "absolute temperature" is the best text from which to start. So long as he deals only with observations, tables, maps, and diagrams, a meteorologist is apt to say, "Why worry me about absolute temperature? Why not let me measure temperature in the Fahrenheit scale which I understand?" To which the reply is another question: "How do you deal with the expansion of gases? Do you work out your questions of the expansion of gases on the Fahrenheit scale?—in schools they never teach that. How do you compute the density of air?" The whole of the circulation of the atmosphere depends upon the gaseous laws and upon variations of density, they appear in almost every meteorological calculation. You cannot take a single step in the explanation of the phenomena of weather without them; and if you wish to get beyond the stage of the schoolboy the gaseous laws must be constantly in your mind. You will require also to be familiar with the dynamical and thermodynamical properties of gases, and, still more recondite, the thermodynamical properties of moist air: it is useless to think about the formation of rainfall as a physical process without them. The great law of the conservation of energy must be your familiar friend, and absolute temperature then becomes a method of abbreviation.

There are other subjects which are just as valuable. One of the most important is an experimental knowledge of the mechanics of solids and fluids, fluid pressure, gravity and the motion of bodies under gravity in various circumstances; the motion of bodies under balanced forces, a section of dynamics which is very inadequately treated in text-books for schools and colleges. They are apt to confine themselves to motion in a straight line under no forces or under a constant force, because these lend themselves to easy computation; but the motion of the atmosphere never agrees with that limitation, and that form of simplification is impossible for a meteorologist. Then again the text-books are apt to leave out friction in order to make computation easy. Nature never leaves out friction and yet does the necessary computation without difficulty. If our friends in the colleges would only deal with experimental mechanics instead of limiting themselves to hypothetical mechanics, the comprehension of the phenomena of weather would be much easier. They probably forget that, like all other children, they began life with experimenting upon gravity in their cradles, to the worry of their nurses who had repeatedly to pick up things for them to drop once more.

There are some dynamical principles of universal application in meteorology which are only dealt with in colleges in the recondite region of rigid dynamics, but the results in nature are plain enough, and people who really understand them could, with the aid of practical illustration, bring their comprehension within the range of the meteorologist. Another great branch of dynamics in which we are interested is eddy-motion. We cannot pursue the study of meteorology very far if we ignore it. It is also very difficult, but even difficult subjects can be dealt with by apposite illustration.

Since Maxwell died, so far as I know, there has been nobody who has tried to put scientific reasoning in a form which could be comprehended by people unfamiliar with the forms of mathematics. By his *Theory of Heat* and *Matter and Motion* he opened a way which nobody follows, unfortunately for the amateur who wants to understand things.

There is the great subject of solar and terrestrial radiation. It is very difficult, but it is of such vital importance to us that, difficult or not, we must learn something of it.

Another great branch of the subject is meteorological optics—according to the *Scientific American* we are very ignorant about it in this country, and that may well be true, for the standard works on the subject are not English, and we have no one to make a text-book for us. It implies understanding something of refraction and diffraction and dispersion, all of which can be most beautifully illustrated by experiment. Since light consists of wave-motion, we might include with meteorological optics the phenomena of sound in the atmosphere, which also consists of wave-motion, the peculiarities of its transmission and their relation to the state of the weather.

And finally atmospheric electricity, ionisation, and lightning, the mysteries of the electric charges and discharges of the atmosphere with wireless telegraphy as a method of recording.

Thus, the equipment for which a fully armed student of atmospheric physics will find a use is rather formidable; it is beyond the ordinary resources of the gardener or the schoolboy, but it is not by any means necessary to have the whole complete before taking up some of the problems of the real atmosphere. Let us go back and consider how things might be arranged.

Meteorological optics with sound and atmospheric electricity may be regarded as separate sections that can be treated independently. So far as we know, the phenomena which are included in those sections are incidental to the general circulation; they do not transfer much of its energy, though the market value at current rates of the electrical energy of a single mile of lightning flash has recently been estimated by Mr R. A. W. Watt at £900, and there are many miles of lightning-discharges in the course of a year. For these sections all that we need is that enough people shall be interested in meteorology to make it worth while for some enterprising publisher to provide books on the subjects, specially written for meteorologists with the necessary physical introductions.

But we want at once a masterly chapter on radiation, because the whole of the circulation owes its motive power, though not the details of its form, to the radiation received from the sun. The facts and figures about the relation of radiation to the atmosphere are multitudinous. They are to be found in the literature of physics, and they have been co-ordinated, but not in a way that students of the atmosphere can readily follow.

The rest of the subjects mentioned, together with the observations, tables, maps, and diagrams of Meteorology for Schools, form the groundwork of the study of the physics of the atmosphere. Let me attempt briefly to indicate what a schoolboy should do to make it his own and qualify himself for studying college-meteorology.

First of all, he might get a slide-rule and become familiar by its use with what it all means. It includes trigonometry, the practical measurement of angles, and logarithms. Logarithms are particularly important, because the laws of nature have given the atmosphere a character which is peculiarly logarithmic. As one comes downward from external space to the solid earth by equal steps the pressure and density of the atmosphere progress by equal logarithmic increments, slightly modified by considerations of temperature and humidity. So logarithms are not merely a mathematical device for doing sums; they are a natural reality.

Then the laws of mechanics and of hydrostatics; the properties of motion of solids and fluids studied experimentally, including the phenomena of wave-motion and of eddy-motion, even if we cannot put them in the form of algebraical equations. These he will bear in mind while he is collecting and arranging a set of photographs of clouds of all sorts and varieties. And he will not omit to study the forces which are due to the flow of air or water past solid obstacles and the effect of air upon falling water-drops.

And, finally, the science of heat; thermodynamics and the laws of energy: that has been set out for us in a way that leaves little to be desired in Preston's

Theory of Heat. It needs an additional chapter on the thermodynamics of a mixture of air and water which has been set out by Hertz and subsequently by Neuhoff on the assumption that the reader is familiar with the manipulation of differential equations. But the differential equations only express in algebra facts of the kind with which, in reality, even the schoolboy is familiar in the form of graphs. Maxwell has had no successor in the endeavour to substitute diagrams for differential equations, because the teaching and learning of the subject have been practically confined to people who aspire to become physicists by profession, and for them it is a sign of weakness to miss an opportunity of using a differential equation; but when the nation shall arrive at the conclusion that Meteorology for Colleges is a subject which demands consideration it need not be doubted that a successor to Maxwell will be found.

Though the gap between the Meteorology of Schools and the Meteorology of Colleges is a wide one it is worth while to make an attempt to bridge it, because the explanation of natural phenomena is one of the irrepressible instincts of mankind. There is all the difference in the world between the physical explanation which gives a fully reasoned relation between cause and effect, which deals with measured quantities, and the imperfect explanations that may be fairy tales; and even if the old fairy tales should in the end prove substantially true there is much satisfaction to be derived from knowing exactly what they mean.

There is a large section of meteorology which is between that of schools and that of colleges. It is the section which deals with the arithmetical manipulation of accumulated facts, with the detection of periodic changes by the methods of harmonic analysis or otherwise, and the detection of the relation of different series of numbers by the methods of correlation. The actual processes involved are not beyond the capacity of a schoolboy, and the proofs of the formulae employed are within the reach of the highest classes in schools. But the selection of the materials for work of this kind requires judgment and experience. Any one who plunges into it without careful guidance is very apt to find that he has wasted time by proving something which was already known, or leaving things as vague as they were before. This kind of work is best undertaken by a student working under an experienced teacher of meteorology hardly to be found at present in colleges and not frequently in schools.

2. PRESSURE IN ABSOLUTE UNITS

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FROM time to time, and especially within the last few years, the adoption of absolute units for representing atmospheric pressure has been urged on scientific grounds, and there is a general consensus of opinion that absolute units are the most suitable for dealing with meteorological theory, especially n relation to the upper air.

Through circumstances which are not altogether within my own control I have had to face the adoption of absolute units as a practical question and also as an educational question. In fact, I have had to ponder over replies to the following questions:

What units for pressure and temperature should be adopted in the publication of monthly values of pressure for a *réseau mondial?*

What units should be employed by lecturers and teachers who wish to interest students of mathematics and physics in the development of meteorological science?

What graduation should be employed for a barometer in order to commend most effectively to the wider public the results of meteorological study?

I find the answer to all these questions in absolute units on the C.G.S. system, with only an outstanding uncertainty as to whether the millibar or the centibar is to be preferred.

Perhaps I had better explain that the *bar* represents the C.G.S. "atmosphere," that is, a pressure of 1,000,000 dynes per square centimetre, the dyne being the C.G.S. unit of force. The dyne is the force which produces an acceleration of 1 centimetre per second per second, in a mass of 1 gram. The weight of m grams when the gravitational acceleration is g centimetres per second per second, is mg dynes. The bar is approximately equivalent to 750 millimetres, or 29·5 inches, of mercury at 0° C. and standard gravity. The centibar is one-hundredth, the millibar one-thousandth, of the bar.

It is quite possible that I may be to some extent affected by unconscious bias in favour of the ultimate application of theory to practice. If absolute units are the best for theory, they are the units of the future; for the practical applications of meteorology must ultimately be guided by theory, just as those of astronomy are at the present day. For me this supplies the answer to my first question. The time is coming, if it has not already come, when students of meteorology will deal with the earth as a whole on the basis of observations and will recognise that anything short of that is inadequate for the solution of the more general problems of climate and weather.

To my second question, as to what are the best units for educational purposes, there is only one answer. So far as the United Kingdom is concerned, in all schools and colleges, wherever the elements of mathematics, physics, and chemistry are instilled into the rising generation, they are in association with the metric system as a part of scientific education. Two consequences result therefrom: In the first place, a complete divorce of all scientific experience from the meteorological practice of everyday life, a divorce which may perhaps be sufficiently illustrated if I say that in the laboratory a water-bath of 98° is a very different thing from bath-water of 98° in everyday life. The whole of the disastrous effect of this divorce is hardly to be appreciated by those who have nearly accomplished their life's journey with comparative success in spite of that disadvantage, but that is no reason for disregarding its importance to the young, and therefore let me call special attention to another aspect of it.

Between professors and students of the mathematical and physical schools of our universities there is a "freemasonry," of which the use of metric units is a sign and from which the students of meteorology are apt to find themselves excluded. To express my meaning in the fewest words, let me say that if in a country assembly for the advancement of science, an unknown stranger should get up and speak in metric units, the initiated physicist would at once say "he must be one of *us*," and the uninitiated meteorologist would say "he is one of *them*"; but if he should begin his discourse by speaking in inches and grains, the physicists would at once say "we need not listen—there can be no dynamics or physics in this," and in the most out-of-the-way meteorological assembly, if any one should be heard speaking in metric units, he would not be set down as an eccentric or a crank, but as a person with exceptional scientific associations.

This being so, what should be the line of action of a meteorologist who lays claim to some portion of the scientific spirit? Surely this—not to remain in the isolation that excludes us from the sympathy of fellow-workers, but to turn the tables upon our friends and say to the grand masters of our cult, "We will accept a metric system, but we cannot accept your millimetre, because when we make a change we must take care not to perpetuate the unscientific practice of representing the pressure of the atmosphere by a length. We know that the millimetre which you use is not really a length at all, and is really only a millimetre under conventional conditions of temperature and latitude which never occur together, but our students, who have yet to learn that important fact, will have clearer ideas from the start if they do not begin with that confusion. We are prepared to do what physicists have often aspired to do, but have not had the courage or coherence to carry out, namely, to use pressure units for pressure measurements and leave length units to measure lengths with. Nor can we accept your centigrade scale with the freezing-point of water as its zero. We cannot let our students adopt the conception of negative temperatures, which is a survival of the time anterior to the conservation of energy and which has sooner or later to be explained away with much labour and practical inconvenience."

Let us now deal with the third question: What kind of barometer should be put before the general public with due regard for the teachings of modern meteorology? We know that it is still the practice to sell barometers with the customary legends:

28·0	28·5	29·0	29·5	30·0	30·5	31·0 inches
Stormy	Much rain	Rain	Change	Fair	Set fair	Very dry

and that many newspapers reproduce day by day a barometer dial of this kind. On metric barometers we find the same legends, but "Change" is opposite to 760 millimetres instead of 29·5 inches, and the steps are 10 millimetres instead of half inches. That is in itself sufficient condemnation of what on other grounds is quite intolerable, and in these days we want to suggest some alternative that will not spoil the instrument-makers' trade, nor yet convey to the countryman misleading ideas.

The first idea that an official meteorologist would suggest is that no countryman would have done his duty by the atmosphere unless he had compared his local reading with that of the corresponding issue of the daily bulletin. To do that he must reduce his readings to sea-level, so, absolutely, the first requirement is a simple means for giving, with sufficient approximation, the sea-level pressure. The next idea to be inculcated is that the actual pressure of the atmosphere at the moment does not matter as a general rule, but only the changes which are taking place, and which can be watched locally with great advantage. What could be better for this purpose than to mark some point within the range of the barometer 100 and note the differences from that point as percentages? Coming to details, it can only be regarded as providential that the point on the barometer against which the word "Change" is inscribed, being 29·5 inches, corresponds almost exactly with 100 centibars; consequently the temptation to use centibars and write 100 there is irresistible. Then obviously we must make the range of the dial or the tube big enough to show the changes which are to be expected in the district in which it is to be used, and the countryman will at once realise within what percentages of the middle value the pressure has varied in the past, and therefore may be expected to vary in the future. It is curious that 100 centibars, although not the mean value of the sea-level pressure, is in the middle of the usual range, and is, in fact, the middle line of the ordinary record-sheet of a Richard-barograph, which is marked 75 centimetres or 29·5 inches.

By way of suggesting that it is variations of the barometric pressure which count, and not the particular level, we can give the frequencies of occurrence of different barometric pressures, so that the observer can see for himself whether conditions are normal or exceptional, and so keep an eye on the working of his instrument as well as on the weather.

I have set out these suggestions in a *Land Barometer* (Fig. 1), with a rotating circle for reduction to sea-level. It is not necessary to enter into any further explanation; what is set out on the dial ought to be self-explanatory. But I ought to say a word about the frequencies. I cannot now recall where I got the figures which are engraved on the first dial. I have made new figures for subsequent specimens, which give the average frequency of barometric