COMPTES RENDUS

OF

OBSERVATION AND REASONING

COMPTES RENDUS

OF

OBSERVATION AND REASONING

BY

J. Y. BUCHANAN, M.A., F.R.S.

Commandeur de l'Ordre de Saint Charles de Monaco

Vice-Président du Comité de Perfectionnement de l'Institut Océanographique
(Fondation Albert Ier Prince de Monaco)

"Prove all things. Hold fast that which is good."
I Thess. v. 21

Cambridge:
at the University Press
1917

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Published in the United States of America by Cambridge University Press, New York

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107653580

First published 1917
First paperback edition 2014

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-65358-0 Paperback

PREFACE

AS the title of this volume indicates, the book consists of "accounts rendered" of work done at different times, in different places and on different subjects.

In republishing papers, many of which are of almost ancient date, it was thought advisable to accompany them by explanatory notes and comments. As it was inconvenient to introduce these in the text, they have been embodied in the Contents, which form in fact a summary of the work.

The Contributions to Newspapers concerning matters of public interest at the time have been reprinted because they are of public interest still.

Of the scientific communications the most important are those concerning the Natural History of Steam and Ice, and these have been reprinted in their original form, although this has involved some reduplication of matter. This has been accepted on account of the importance of the experiments and of the consequences which follow from them and of the apparent unwillingness of the scientific public to make use of them.

In the *Chemical and Physical Notes*, which formed part of the *Antarctic Manual* of 1901, will be found a résumé of my experiments in the domain of Inorganic Natural History which, from my own experience, I judged would be found useful by the Chemists and Physicists of the Expeditions for which the *Manual* was prepared.

It was conveyed to me through an old friend and former colleague that this contribution to the *Antarctic Manual* had done much to retard the Standardisation of Research. I took it as a compliment. To standardise research is to limit its freedom and to impede discovery. Originality and independence are the characteristics of genuine research, and it is stultified by the acceptance of standards and by the recognition of authority.

J. Y. Buchanan.

26 *May* 1916.

CONTENTS

PAGE

No. 1. RECENT ANTARCTIC EXPLORATION. (From the *Quarterly Review*, October 1906.) 1

The Belgian Expedition in the "Belgica" was the first to winter within the Antarctic circle 1

The Newnes Expedition, under Captain Borchgrevink, was the first to winter on land within the Antarctic circle. He explored the Ice-barrier and discovered the creek in it from which, later, Amundsen started on his journey, when he reached the South Pole. When these two expeditions were returning, the British Expedition in the "Discovery" under Captain Scott and the German Expedition in the "Gauss" set out 2

A year later the Scottish Expedition, under Dr Bruce, sailed in the "Scotia" 3

A Swedish Expedition, under Nordenskjöld, and a French Expedition, under Charcot, started for Graham's Land later 5

The "Challenger's" search for Wilkes' Termination Land in 1874 6

The "Gauss" frozen in at the beginning of winter . . 7

Scott's Expedition follows the route to the South taken by Sir James Ross in 1841–43. Remarkable difference between the appearance of Mount Melbourne and Mount Erebus in 1902 and in 1841 9

Ross' description of the Ice-Barrier and the Parry Mountains 10

Trustworthiness of Ross' observations: in appraising such observations, their date is of small importance; the determining factor is the competence and the experience of the observer 11

Demonstration that the Parry Mountains exist where Ross reported them to be 12

Confirmed by Armitage 13

Evidence to show that Ross' "Appearance of Land" reported in February 1842 was the land seen by Scott in January 1902, and named by him King Edward VII Land . 15

PAGE

The "Discovery" in winter quarters; mild weather . 16
Remarkable disappearance of ice in winter . . . 17
Scott's farthest South 82° 17′ S. reached 28 December 1902 18
Armitage's remarkable winter journey 20
Probability that the Barrier ice-sheet is a self-contained *névé* or *firn* situated at, and, to a great extent, below the level of the sea 21
Extensive melting of the ice of the Ferrar Glacier in January 1902 22
Evidence of the conservative influence of an ice-sheet on the land surface beneath it 23
The "Discovery" sails for England 24

No. 2. CHEMICAL AND PHYSICAL NOTES. (Contributed to the *Antarctic Manual*, 1901.) 25

In preparing these notes it was assumed that the Chemist and Physicist of the Expedition would be a man of considerable laboratory experience and would be fully instructed and practised in all routine observations before the start of the Expedition. These notes have reference rather to observations by the way, a class of work which is both useful and fascinating. In putting them together, the chemical and physical phenomena likely to be met with in Nature have been regarded and treated as facts in Natural History of which Chemistry and Physics are branches. I have endeavoured to imagine myself as filling the post and to recall from my experience the kind of phenomena which I should expect to encounter, and to frame working directions for myself with a view to their treatment and elucidation. In doing so I have avoided all hypothetical matter and confined my directions to matters of observation and experiment.

Low oceanic temperatures; the extensive area of very cold water which occupies the bottom of the sea all along the East Coast of South America from the Straits of Magellan to the Equator is an oceanic feature which calls for thorough study 26
Importance of the determination of the density of this very cold water 27
Freezing Temperature of average Sea-water . . . 28
Relation between freezing-point and percentage of Chlorine 29
Sea-Ice as met with in Polar Seas 30
Weyprecht's description of the freezing of the sea in which the "Tegetthoff" was imprisoned 31

PAGE

Demonstration that the Ice produced by freezing Sea-water and similar solutions is pure ice 33

Analogy between Snow and Sea-ice. The freezing-point of a saline solution is analogous to a Dew-point: Cryohydrates 35

De Coppet's experiments on the freezing-points of saturated solutions 37

Experiments in the Engadine in Winter on Cryohydric points 40

Cryohydrates of Salts forming Isomorphous mixtures . 43

Land-ice and the mechanics of Glaciers 45

Importance of the study of the Grain of the Glacier. . 47

Sea-ice contains much Brine and flows easily; Land-ice contains little Brine and flows with difficulty 49

The whiteness of the surface of a Glacier is a secondary feature, due to the disintegration of the Grains by the Solar Radiation 50

Study of boiling mixtures of steam and salts; analogous to freezing mixtures of ice and salts 51

The boiling-point of a substance is the temperature at which it, as a vapour, condenses on itself as a liquid, and as a liquid, evaporates into itself as a vapour 55

Comparison of Barometer and Hypsometer 56

To determine the boiling-point of a liquid, it should be boiled by its own steam 61

Data relating to boiling mixtures of NaCl, Table VII . 63

The thermal law, called Blagden's, is applicable to the boiling-points as well as to the freezing-points of solutions . 66

The temperature at which steam condenses on a perfectly dry, solid substance is unknown, but when it is moistened in the slightest degree even with dew, the temperature of condensation is that of water boiling under existing conditions . 67

Proof that steam produced by a boiling solution must quit it at the temperature of the boiling solution. Meteorological observations and instruments 68

The rate of cooling, or its reciprocal, the term of cooling, of a thermometer, is as important a constant as the position of the ice-point 69

The work on this subject by Newton, Lambert and Leslie is classical.

Term of cooling is an index of thermal *nimbleness* . . 70

The logarithmic law 75

Causes of deviation from it 76

Effect of silvering the bulb 79

Difference between a calm in-doors and a calm out-of-doors 80

PAGE

Thermometer as an Anemometer 81
Thermometer as Calorimeter 82
Estimation of the thermal mass of the bulb of a thermometer by mensuration 83
Relation between the volumes of mercury and glass in the bulb 89
Particulars of air thermometer 92
Application of calorimetry to hydraulics.
Temperature of insolation 94
When the thermal mass of the bulb of a thermometer and its term of cooling are known, it can be used as a solar calorimeter 95
Example of the method of determining the calorific power of the sun's rays, which strike the bulb of a thermometer and are absorbed by it, and of the difference between different thermometers in this respect 96
Convenience of compound names to express compound units, such as gramme-degree for calorie 98
Value of solar constant obtained with the steam-calorimeter in Egypt, and variation of the same during the total eclipse of the sun, 17 May 1882 101
The necessity of the knowledge of calorimetric factors in connection with the use of the Barometer.
Advantage of Fahrenheit's thermometric scale. The coefficient of thermal expansion of mercury is 1/10,000 per degree Fahrenheit 102
The meteorological records of all inhabited places on the earth can be kept in numbers having the same sign, with very few exceptions 103
The temperature of the air immediately above the sea surface in tropical regions is almost as constant as that of the water 104
Effect of change of Force of Gravity on the Pressure of the Atmosphere and on the Height of the Barometer . . 105
Table XVIII gives the true atmospheric pressure and the boiling-point of water corresponding to a Barometric Height of 735·5 millimetres at 0° C. and at the sea-level in different latitudes 110
Change in the force of gravity affects the pressure of the atmosphere but not the height of the Barometer . . . 112
Rule for detecting the deviation from the normal of the local force of gravity by simultaneous observations of the standard height of the Barometer and the boiling-point of water 114

PAGE

Suggestion of the use of the Hypsometer at sea for detecting changes of depth in the ocean 115

Advantages and disadvantages of the Aneroid barometer

Examples of Rapid Variations of Atmospheric Temperature, especially during Föhn 116

The curve of the temperature of the air drawn by a recording thermometer is serrated during the day and smooth during the night 117

Characteristics of Föhn 118

Föhn is independent of absolute height; it depends on difference of height 119

Well-marked Föhn at sea-level in Scotland 120

Effect of Föhn in Polar regions 122

Puffs of air of temperature higher than that of the human body are characteristic of well-developed Föhn 123

Necessity of acquaintance with the Term of Cooling of the thermometer when used in determining the temperature of the air during Föhn 124

Table XXII. Temperature observations at equal altitudes over the Morteratsch Glacier and on the mountain west of it 125

Remarkably high temperature of the air immediately contiguous with the ice of the glacier during Föhn 126

Observations of the temperature of the air when ascending Piz Languard during Föhn 128

Note. The Föhn described in the paper is fine-weather Föhn, with cloudless sky and strong sun. The Föhn occurring with overcast sky and rain is not treated. It is this Föhn particularly that wastes glaciers.

No. 3. On Ice and Brines. (From the *Proceedings of the Royal Society of Edinburgh*, 1887, Vol. XIV, p. 129.) 130

This investigation was undertaken in order to determine experimentally whether the salt which occurs in the ice formed by freezing sea-water and other saline solutions is a part of the solid ice or belongs to the liquid brine which adheres to the ice. The fundamental principle on which the experiments were based is that, if a saline solution, such as sea-water, is partially frozen and the temperature of the mixture is observed, then, if the ice so formed is pure ice, it may be removed and be replaced by pure ice of independent origin, such as snow, having the same temperature, and if heat is then supplied, the snow will melt in the solution at the same temperature as that at which the ice which was produced in the solution was found to melt. This was found to be the case. As a corollary,

PAGE

it follows that the temperature at which pure ice melts depends on the medium in which it melts. The subject is dealt with under two heads; namely: (*a*) the temperature at which sea-water and some other saline solutions freeze, and the chemical constitution of the solid and the liquid into which they are split by freezing; and (*b*) the temperature at which pure ice melts in sea-water and in a number of saline solutions of different degrees of concentration 133

An important condition of success in these experiments is to freeze the solutions gently. The temperature of the freezing bath was usually about 2° C. below the freezing temperature of the solution.

Table I. Freezing sea-water. Analyses of Fractions. Constancy of Ratio SO_3 : Cl in the original sea-water, in the ice formed, and in the residual Brine 135

Table II. Calculation of Ice formed on the basis of the salinity of the original water and of the residual Brine . 136

Table III. Agreement of weight of ice formed calculated from the salinity of the solution and from the thermal exchange during freezing 137

Impossibility of solidifying sea-water by any cold occurring in Nature.

Melting of pure ice in sea-water and in other saline solutions 138

Demonstration that the mere density of the solution has no direct connection with the lowering of its freezing-point . 142

Experiments with concentrated solutions of hydrochloric acid and sulphuric acid 143

Demonstration that the experiments prove that the ice formed by freezing sea-water and similar saline solutions is pure ice and that the salt belongs to the brine 144

Application of this discovery to the phenomena occurring in the freezing of fresh water and other solutions of very high dilution 147

No. 4. On Steam and Brines. (From the *Transactions of the Royal Society of Edinburgh*, 1899, Vol. XXXIX, Part III, No. 18.) 151

The object of the research was to study, generally, the natural history of boiling mixtures of steam and salts, analogous to the freezing mixtures of ice and salts; and, particularly, to settle the question of the temperature at which steam leaves a boiling saline solution. The experiments were continued so as to give the concentration and the

PAGE

boiling temperature of solutions of different strengths below that of saturation 151

If a solution can condense steam from the outside, it necessarily must be able to condense its own steam, because the two substances are identical. Therefore, steam introduced from the outside must continue to raise the temperature of the solution even after it has passed above the temperature of the boiling water from which it has been obtained and until the temperature of the solution has been raised to that at which the solution itself liberates steam of atmospheric pressure, and, by consequence, allows steam of atmospheric pressure introduced from the outside to pass freely through it. It follows further that, to determine the boiling point of a saline solution, it suffices to pass a current of steam of atmospheric pressure through it until it raises the temperature of the solution to a maximum, and that is the boiling-point of the resultant solution.

The following law holds:—The temperature at which steam condenses depends on the nature of the medium in which it condenses; and the temperature at which it is generated depends on the medium in which it is generated; and the temperature at which steam condenses in a given medium is that at which it is generated in the same medium; the pressure in all cases remaining uniform.

The above method of determining the boiling-points of saline solutions gives, easily, results of the greatest precision. When the solution is boiled over a flame the results are irregular and untrustworthy 152

Preliminary remarks on the experiments to be made, and examples of the solubilities of some salts at the boiling temperatures of their saturated solutions 154

Apparatus and method of experimenting 155

The result to be obtained from each experiment is the difference between the temperature of pure saturated steam and the maximum temperature produced by the condensation of such steam in the brine, or the mixture of salt and brine. Therefore, the temperature of pure saturated steam must be observed at the same time as that of the boiling brine. It follows that for the conduct of these experiments observation of the barometer is unnecessary 158

Importance of the relative dimensions of the entry and exit of the steam-tube: experiment which proves the efficiency of the steam-tubes used 159

It is essential that the thermometer and the inside of the

PAGE

steam-tube be chemically clean: Soap is used for this purpose, and the best way of using it is described 160

The thermometers used and their verification . . . 161

The general order of the experiment 162

The use of steam for drying the inside of complicated glass apparatus.

As the result of an experiment, we obtain the temperature of ebullition of the saturated solution and its concentration,—also the boiling temperature and the concentration of a series of more dilute solutions 163

Determination of the thermal capacity of the apparatus with steam 164

Thermal specification of the apparatus 165

Localities where experiments were made 166

The altitudes above sea-level of these localities are given: they range from 87 metres at Edinburgh to 2733 metres in the Engadine 167

The salts used in the research 168

Detailed description of the experiments, the results of which are recorded in Tables II and III 169

Description of Table IV which contains the greater part of the results of the research 171

The importance of the physical meaning of the expression $W(t-T)$.

In the equation $W(t-T)=$constant, we have Blagden's law of the lowering of the freezing-point of saline solutions extended to the raising of their boiling-points 173

Table V gives the results of experiments made with dilute solutions.

Exclusion of chloride of rubidium from the Table on account of impurity of the sample. As regards the metallic component it was, as it professed to be, "spectroscopically pure," but it contained sulphate as well as chloride of rubidium. This affords a good example of the necessity of testing chemicals which are used in work that is to be published, no matter how great the reputation of the furnisher of the preparation may be.

Table VI is derived from Table V and gives the values of $W(t-T)$ for even temperatures.

The results given in Table IV in terms of temperature, are repeated in Table VII in terms of the equivalent barometric pressure 176

Table VIII gives the vapour tension of water in kilograms per square centimetre at temperatures from 90° C. to 120° C.

PAGE

Observations on the behaviour of mixtures, and particularly, of isomorphous mixtures of salts 177

The device of the elastic tank of uniform depth. It provides a standard of comparison between the chemical effect of a dissolved salt and the mechanical effect of increased pressure upon the boiling temperature of water. It furnishes the extra load required to press on the surface of the pure water in the tank so as to prevent ebullition at the temperature at which a given weight of salt dissolved in the water would produce the same effect. It furnishes the mechanical equivalent of the weight of salt, in so far as the raising of the boiling temperature of water and the resistance to steam pressure are concerned 178

The specific properties of the dissolved salt are most pronounced in its concentrated solution 179

The mechanical experiment with the elastic tank represents the chemical case where the increase of steam-tension neutralised by the salt is proportional to the quantity of the salt. A case of the use of the elastic tank is described fully . . 180

Demonstration of the identity of Blagden's Law with the thermal law of mixture 182

No. 5. THE SIZE OF THE ICE-GRAINS IN GLACIERS. (From *Nature*, August 22, 1901, Vol. LXIV, pp. 399–400) . . . 226

This investigation was undertaken in order to ascertain by actual observation the maximum size of the ice-grain in a particular region of a particular glacier, and the gradation of size of the other grains from this maximum downwards to the minimum occurring in the block of ice dissected. In all published descriptions it was admitted that the shape of the ice-grain is irregular, but in dealing with the size of the grains at any part of a glacier, the descriptions were frequently incompatible with the geometrical principle that, if the shape of the grains is irregular, there must be grains of practically all sizes from the maximum downwards, in order that the ice may fill the space of a solid block.

The blocks dissected were taken from the Glacier des Bossons in the Chamonix Valley and from the Aletsch Glacier at the Mergelin Lake 227

Table I gives the weight in grammes of single ice-grains . 228

Table II enables a view to be formed of the average size of the grains in a block 229

The action of solar radiation on glacier-ice is twofold: it produces disarticulation and lamination 230

PAGE

Glacier-ice is protected from sun-weathering by ice and by water 231

It is the dependence of the melting-point of ice on the nature of the medium in which it melts that enables glaciers to move under the action of gravity 232

No. 6. ICE AND ITS NATURAL HISTORY. (From the *Proceedings of the Royal Institution of Great Britain*, 1909, Vol. XIX, p. 243) 233

Recapitulation of principles and laws established in earlier work and applicable to the matter handled in this lecture . 233

The freezing-point of a substance is defined to be: the temperature at which it, as a liquid, passes into itself as a solid; and its melting-point to be the temperature at which it, as a solid, passes into itself as a liquid 238

When ice is melting in a mixture of ice and water, the temperature of the water must be a little higher than that of the ice, else there would be no inducement for heat to pass from the water to the ice; similarly, when ice is being formed in a mixture of ice and water, the temperature of the water must be a little lower than that of the ice produced . . 239

The temperature at which ice begins to take form in water which is cooled when in contact only with itself, or with a solid other than ice, has not been determined, and is in fact uncertain. The moment the smallest particle of ice is present, the water has the opportunity of passing, as a liquid, into itself as a solid; but not till then 240

It is probable that in nature ice never melts and water never freezes exactly at 0° C. The law which regulates the melting of ice in nature may be stated as follows:—If the pressure is constant, it varies with the nature of the medium; and if the nature of the medium is constant, it varies with the pressure.

The influence of salt in inducing the melting of ice at temperatures between 0° C. and its Cryohydric point furnishes a quantitative explanation of observed anomalies in its physical constants.

The belief that ice, at temperatures near 0° C., does not contract but expands on being cooled, has been maintained by experienced observers, such as Hugi, Petzold and Pettersson. Their observations were exact but their interpretation of them was faulty. When due weight is given to the influence of the medium, the anomaly disappears, and it is found that ice does not behave in the capricious way supposed, but conforms to the usual custom, by expanding when warmed and contracting when cooled 241

PAGE

Quotations from the paper 'Ice and Brines' in illustration of this 242

These quotations from my paper of 1887 are given at length, because, though published so many years ago, it appears to have been but little read. I know of no treatise on natural ice in which the dependence of the melting temperature of ice on the nature of the medium in which it melts is even mentioned, still less taken into account. For these reasons, I have made the development of this important subject the principal feature of this Lecture 244

After stating the constants involved, the cryoscopic principle established in the paper on 'Ice and Brines' is applied to the discussion of the apparent variations of volume of a block of ice, the volume of which at 0° C. is 1000 cubic centimetres. It contains 1·5105 gram NaCl, diffused through it, and it is provisionally assumed to be in the inert state, in which it is deprived of the power to induce the melting of ice at temperatures between 0° C. and its cryohydric point (−21°·72 C.). If the temperature of the block containing the inert NaCl be reduced to −23° C., its volume will be reduced to 996·320 c.c., and as the temperature is below the cryohydric temperature, the salt is by nature inert. At such temperatures ice and common salt are indifferent to each other. Returning to the initial state, let the temperature of the block be reduced to −21° C., the ice remaining inert. The volume of the ice will then be 996·64 c.c. Let the NaCl now recover its activity, it will melt 5·628 c.c. ice producing 5·160 c.c. water under a contraction of 0·469 c.c. so that the apparent volume of the ice at −21° C. is 996·171 c.c. By the aid of Table I and the other constants, we can calculate the composition of a block of ice of any weight or volume which contains 1·5105 gram NaCl. The results of such a calculation are given in Table II for a block of ice having the volume 1000 c.c. at 0 C. The results are given graphically in Curve B, Fig. 1. This curve has the remarkable feature of two acute angles, giving the appearance of the letter Z at the cryohydric temperature. Above this temperature the ice expands with heat, but at a gradually diminishing rate, until at −7°·0 C. the increase of volume due to simple expansion of the ice is exactly balanced by the contraction due to induced melting. At this temperature the coefficient of apparent expansion changes sign and becomes negative. Therefore, the coefficient of apparent thermal expansion of this ice changes sign three times when it is warmed from a temperature below the cryohydric point of solution of

PAGE

chloride of sodium to that at which liquefaction is complete; and the actual facts of the apparent expansion have been accounted for step by step by the cryoscopic reaction of NaCl on ice between −21°·72 C. and 0° C. 249

For blocks of ice which contain per 100 parts by weight of ice less than 29·97 and more than 1·7164 parts of NaCl, the coefficient of apparent expansion is negative at all temperatures above −21°·72 C. For solutions of higher dilution Table III gives the critical temperature at which the coefficient of apparent dilatation changes sign and becomes negative.

This Table shows that in the case of ordinary potable waters this critical temperature is sufficiently removed from the temperature of congelation to be easily determined, and it furnishes the best method of arriving at the concentration of fresh water, or solutions of very high dilution. Thus, when the dissolved matter is equivalent to no more than one gram of chlorine, present as chloride of sodium, in one hundred thousand grams of water, the critical temperature is −0°·725 C. The critical temperature of the apparent expansion of ice affords a means of detecting impurity equivalent to quantities of chlorine as small as 1 gram in *ten tons*, and even 1 gram in one hundred tons of water 251

Cryoscopic equivalence between pressure and salinity. This subject has been worked out in much the same way as the similar phenomenon of the elevation of the boiling-point of water by pressure and by dissolved salt, for which we used the device of the elastic tank of uniform depth. In both cases the same Law is found to exist. For a given elevation of the boiling-point in the one case and depression of freezing-point in the other, there is the same approximate proportionality between the area of the surface of the water exposed to the pressure and the volume of the water which holds the equivalent amount of salt 252

Influence of impurity on the apparent latent heat of ice . 255

Size of glacier grains 258

Sun-weathering of granular ice produces white surface of glacier 262

Snow, névé and glacier 263

The grain of lake-ice 265

Characteristics of an advancing glacier 267

Grooving of ice by rock 268

External work of a glacier 270

The real region of mechanical erosion and attrition is the sea-shore 272

PAGE

Advantage of the study of tropical lands.

The rounding of pebbles, generally attributed to the mechanical action of streams, is due to the chemical action of subaerial weathering. When an irregular piece of rock is exposed to subaerial weathering, or any other external chemical decomposing agent, the resultant form of the undecomposed kernel of the fragment is necessarily an ellipsoid . . . 273

Weathering in Tenerife 274

Similar case observed by the Prince of Monaco in the Cape Verde Islands 275

The "Crumble" formation.

This is the name which I invented for my own use in recording the occurrence of a common surface feature of tropical and equatorial regions, when on board the "Challenger." I found in all such countries that the rocks were decomposed to a depth of many metres, the residual material often remaining in situ, with such a fresh appearance that it was difficult to imagine that it could be anything but unaltered rock. It was only necessary, however, to touch it with a stick or even with the fingers, for it to "crumble" into fragments of all sizes down to sand and clay. In almost every place within the tropics visited for the first time the rocks were logged as consisting of "the crumble formation." Outside of the tropics this formation occurs only in a rudimentary form. The crumble formation owes its existence to a high atmospheric temperature and to humidity. It is the typical formation produced by the subaerial weathering of rock in situ. Very slight mechanical disturbance is sufficient to cause degradation under gravity, with the production, first of taluses; then as the taluses undergo further gravitational degradation, they flatten out, and the final product of the crumble formation and of subaerial weathering is the pampa, prairie, steppe or desert, which are the native names for the same formation in homologous climatic regions of the earth.

Demonstration that the generally accepted doctrine that rock-fragments, which are found so frequently covering the tops of mountains, are split off from the parent rock by the energy liberated by water freezing in its interstices, is untenable . 278

No. 7. BEOBACHTUNGEN ÜBER DIE EINWIRKUNG DER STRAHLUNG AUF DAS GLETSCHEREIS. (Extract of paper read before the physical section of the Schweizerische Naturforschende Gesellschaft at its meeting at Basel on 6 September, 1910, and printed in its *Verhandlungen*, I, p. 330) 280

PAGE

As almost all my work on ice, outside of the laboratory, was done in Switzerland, and as the Swiss Naturforschende Gesellschaft honoured me many years ago by making me one of its honorary members, I considered it my duty to communicate to it an account of the more important results of my work on the Swiss glaciers. I had also in my mind that in case of there being any doubt about the work, the Swiss were geographically in a better position to verify it than any other people. As the meeting was being held in the principal city of German Switzerland, I made my communication in the German language.

No. 8. In and around the Morteratsch Glacier: A Study in the Natural History of Ice. (From the *Scottish Geographical Magazine*, 1912, Vol. xxviii, p. 169.) . . 283

My first acquaintance with glaciers was made in the summer of 1867, when I visited Grindelwald. Both of the glaciers of that valley were then in the state which they had maintained for more than a century 284

Recent change in the Lower Grindelwald Glacier and in the Rhone Glacier, shown by ancient pictures and modern photographs. These pictures exhibit the wastage which has taken place in less than 50 years. M. Vallot estimates it to amount to one-eighth of the total amount of sinking since the last ice-age 286

Shrinkage of the Morteratsch Glacier in the last few years, exhibited by photographs taken during the period of 1906–1911. The greatest amount of subsidence took place in the very hot summer of 1911, amounting to between 4 and 5 metres, the average being 2·5 to 3 metres.

At the end of the glacier the rate of apparent annual retreat of the ice was less than 2 metres, while, on the western flank, it was nearly 9 metres 288

The principal source of the impurity in the intergranular water is rock-débris 291

Usefulness of the artificial grottos which are met with in all frequented glaciers for the study of glacier-ice in its primary state 292

Intergranular melting of ice and re-freezing of the same . 293

The intergranular moisture or liquid is an important item in the economy of the glacier. It is the mother-liquor of the grain and produces the medium in which the activity of the crystallisation and dissolution of its ice develops itself. Effect of solar radiation on glacier-ice. Its principal effect is the production of the white surface-layer 294

PAGE

Its whiteness is due to the same cause as that of a field of snow, namely discontinuity in the discrete particles or masses of ice of which they are composed. The snow-field is produced synthetically by the atmosphere; the white surface of the glacier is produced analytically by the sun's rays. The internal melting of the ice of the glacier by radiant heat proceeds by the melting of the outer surface of the individual grain 295

If a glacier were exposed only to heat of convection, it would melt with a smooth surface and its colour would be blue. As the sun's rays analyse a piece of glacier-ice, separating its constituent grains, so they continue the analytical process on the isolated grain or crystal and separate it into its constituent lamellæ which are arranged normally to the principal axis of the crystal. The Morteratsch Grotto and the experimental use made of it 296

Important observations made in February 1894 . . 297

Delineation of the grains on the walls of the grotto extends as far as direct skylight penetrates.

Illustration of the state in summer.

Granular feature in winter 298

Hoar-frost produces etched figures of the granulation of the ice, especially on the roof of the grotto 299

Disintegration behind the surface of the walls.

Usefulness of photography inside the grotto. By prolonging exposure views may be obtained of features which the eye cannot detect. The stereoscopic camera is especially useful in the study of the internal disarticulation of the ice, and of other features 300

Nature of the apparent stratification of the ice, which is sometimes visible on glaciers 301

Importance of studying the grotto in spring or early summer 302

Improbability that a ribbon-structure extends through the mass of a glacier.

The case of a glacier which has never been exposed to light 303

Water a protective medium. It is opaque to the rays which disintegrate glacier-ice 304

The Mergelin Lake and its icebergs. They are analogous to those of the Antarctic Ocean 305

The granulation of glacier-ice is best studied at the Mergelin Lake and in the month of July, when the sun is powerful 306

PAGE

Hugi's Fundamental Experiment. A piece of fresh blue glacier-ice, exposed to the rays of a powerful sun, in a very short time crumbles together into a heap of individual ice-grains 307

Hugi's greatest achievement was his *Winterreise ins Eismeer*, in January, 1832, a date which will be for ever memorable in the history of the study of glaciers. Although only a schoolmaster, it was carried out entirely at his own expense. The organisation of it was complete, covering observations in the valley with those which he and his party were to make on the mountain. It lasted fourteen days, and nearly every one of these days is the date of a fundamental discovery in the natural history of land-ice 308

Recapitulation and Conclusion 309

No. 9. On the use of the Globe in the Study of Crystallography. (From the *Philosophical Magazine*, 1895, S. 5, Vol. xl, pp. 153–172.) 313

In this paper the usefulness of the Globe in the study of solid Geometry generally is explained. The term crystallography used in the Title refers to a particular case where polyhedra are limited by certain symmetries.

The blank globe, whether black or white, with the divided circles belonging to it, is a calculating machine, adapted to the solution of all the problems to which the analytical methods of spherical trigonometry are usually applied . . 313

The globes which I used were those of 22 centimetres diameter, which the firm of E. Bertaux of Paris supply. For measuring purposes a system of divided circles of the same radius as the sphere, called the Metrosphere, is supplied. The real usefulness of the globe is not to be learned by theory or precept, but by actual experience in the solution of problems whether the study be astronomy or navigation or geography or crystallography 314

A detailed example is given of the use of the globe as applied to a polyhedron of any number of plane faces, arranged in any way so as to completely enclose the space . 315

When the operation described has been performed, we have on the globe a number of points which form a complete catalogue of the faces of the polyhedron or crystal. Similarly the arcs connecting each pair of poles furnish a catalogue of the inclination of every single face to every other . . . 316

By another graphic process we obtain a catalogue of all the plane angles occurring on the faces of the polyhedron . 317

PAGE

The representation of the faces of a crystal by great circle planes, and that of the edges by diameters, all of which necessarily meet in the centre, facilitates the choice of a suitable system of crystallographic axes 318

A collateral advantage which the student gains by using the globe in this way is the excellent mental discipline which it affords. A very short experience developes enormously the sense of direction. *There is no operation in the geometry of polyhedra or crystals which cannot, with the greatest ease, be performed by the use of the globe*. 319

Postscript containing examples of the use of the globe in dealing graphically with the relations of the faces, edges, etc., of a crystal 321

It is impossible to illustrate examples without the aid of the globe itself and the reader must have one before him in order to make for himself the constructions described. One metrosphere can be used with any number of globes, so that separate details can be worked out on separate globes and combined on others, thus avoiding the risk of mistakes due to overcrowding 325

No. **10.** On a Solar Calorimeter used in Egypt at the Total Solar Eclipse in 1882. (From the *Proceedings of the Cambridge Philosophical Society*, 1901, Vol. xi, Pt 1, pp. 37–74.) 337

While engaged in discussing questions connected with the physics of the ocean, I found the want of definite knowledge of the amount of solar heat which really reaches the surface of the land or sea in a form which can be collected, measured and utilised. There was no lack of actinometrical observations, but I found it impossible from them to obtain the data that I sought. The aim of most observers has been to arrive, by more or less direct means, at what is known as the solar constant, that is, the quantity of heat which is received in unit time by unit surface, when exposed perpendicularly to the sun's rays outside of the limits of the earth's atmosphere. For my purpose the amount of radiation arriving at the outside of the earth's atmosphere was of no importance. What I wanted to know and to measure was the amount of solar radiation which strikes the earth at the sea-level and is there revealed as heat. It is the energy of this radiation which maintains the terrestrial economy. Having the opportunity of accompanying the expedition to Egypt for observing the total eclipse of the sun on May 17th, 1882, I determined to

PAGE

make observations for myself on the amount of heat which could actually be collected from the solar radiation in these favourable circumstances 337

I determined to use a calorimeter which should depend for its indications on change of state and not on change of temperature, and I designed a steam-calorimeter by which the sun's rays should be collected by a conical reflector of definite capacity and be thrown on an axial tubular boiler in which they should be transformed into the latent heat of steam; and the amount of steam so produced per unit of time from water at the temperature of ebullition should be a measure of the rate of heat-receipt from the sun, in the conditions of the experiment.

Locality.

The astronomers chose a spot on the banks of the Nile close to the town of Sohag, and in Latitude 26° 37′ N. for the observation of the eclipse, and experience showed that it had been well chosen. The eclipse was total at 8.34 a.m. on the 17th May 1882, civil reckoning. The maximum duration of totality that was expected was 70 seconds, and, in fact, it lasted longer than 65 seconds. The expedition arrived on the 8th May and I began work with the calorimeter on the 11th and devoted the whole of my time to this work until the 19th May, when the camp was struck. From the outset the calorimeter worked most satisfactorily and the only alteration which had to be made was to replace the original metal dome, as steam space of the boiler, by a glass tube. From the 11th to the 15th May I was occupied in studying the instrument and learning how to use it, in the only way by which this is possible, namely, by setting it to do the work expected of it, noticing deficiencies of arrangement and mistakes made in handling, and rectifying them as they showed themselves. In the course of this educational work valuable preliminary results were obtained, and on the 16th, 17th and 18th trustworthy experiments were carried out with the apparatus in best working order and under very favourable natural conditions 338

Table I gives the sun's altitude and azimuth at noon and at every half-hour on each side of noon until sunset for the date of the eclipse 339

Illustrations of the calorimeter, Figs. 1 and 2 340

Construction of the calorimeter 341

Principal section of the calorimeter, Fig. 3 342

PAGE

In use, the calorimeter is pointed axially to the sun. Method of adjustment to compensate the rotation of the earth 343

General description of an experiment.

When everything was at the temperature of the air and the instrument was pointed to the sun at 2 p.m., the water in the axial boiler boiled in 40 seconds, and it continued to boil so long as the instrument truly followed the sun and as the sun was not obscured. The boiling proceeded with perfect regularity, even when the sun was at its hottest, as on the forenoon of 18th May; and with the glass dome as steam-space everything could be followed minutely 344

The instrument is not intended for "snapshotting." It is essential that the distillation be kept running continuously, and the water produced in successive intervals of time be weighed or measured. If the meteorological conditions are such that the boiling is interrupted, then it is of no use attempting to make any observations. There was no trouble from this cause at Sohag. The sole object of my experiment was to ascertain the greatest amount of heat which can be obtained per unit of time from the sun's radiation at or near the sea-level. Owing to the great latent heat of steam, the immediate feed of the boiler is automatically maintained at the boiling temperature, so that, when in continuous running, the whole heat collected from the sun and thrown on the boiler is used in transforming water into steam of the same temperature 345

Illustration of the calorimeter on equatorial mounting. Fig. 4. 347

Description of the construction of the reflector . . . 348

Table giving the numerical data relating to the reflector used 353

Geometrical construction of reflector, when the position of a point on one of the mirrors and the position and length of the focal line are given. Fig. 6 354

Meteorological observations at Sohag: Table II . . 358

Description of the eclipse 361

It was witnessed from the banks of the Nile by the whole population of Sohag. The most striking and the least expected feature of the eclipse was the appearance, with totality, of a brilliant comet, between two and three sun's diameters from the darkened disc and with a slightly curved tail equal in length to the sun's diameter. Only the astronomers were prevented from witnessing this unique phenomenon, by the nature of their observations, which had to do with one branch

PAGE

or another of solar photography, and with only a minute in which to make them. The principal stars, as well as the comet, were shining brightly during totality: nevertheless, I was able to read the scale of an ordinary thermometer during totality. Two solar protuberances were visible to the naked eye, but to me they appeared to be notches in the dark disc of the moon through which red light was visible. This observation has an important bearing on the interpretation of the phenomenon generally called "Baily's beads." Of all the natural phenomena which I have had the opportunity of witnessing, there is none which produces so powerful an impression as a total eclipse of the sun.

Conditions during the forenoon of 18th May, when the maximum value of the solar radiation was observed with the calorimeter 362

Discussion of the observations 363

Rates of distillation observed on 16th, 17th and 18th May: Table III 364

Graphic representation of the same 369

The weather on each of the three days was very fine, but it was best during the forenoon of the 18th, when the maximum rate of distillation observed was 1·501 cubic centimetre per minute 370

To transform 1·5 gram of water at 100° C. into steam of the same temperature 803 gram-degrees of heat are required; and this is the greatest amount of heat which has been collected by the calorimeter in one minute. The actual collecting area of the reflector is 903·5 square centimetres. Therefore, the heat so collected is equivalent to 8888 gram-degrees per square metre: and 8888 gram-degrees C. suffice for the generation of 16·6 grams steam at 100° C. Therefore, it has been shown by our experiments that, by the use of ordinary mechanical appliances it is possible, under favourable geographical and meteorological conditions, to collect, on a square metre of surface, at or near the sea-level, exposed perpendicularly to the sun's rays, the energy of generation of 16·6 grams of steam per minute, or 8888 gram-degrees of heat, which are equivalent to 3777 kilogram-metres of work: and, as this work is done in one minute, the agent is working at the rate of at least 0·84 horse power. Therefore, the object for which I designed the calorimeter and used it in Egypt was achieved.

Taking the area of a great circle on the earth's surface to be $129{\cdot}9 \times 10^{12}$ square metres, the useful energy received by

PAGE

the whole earth is at the rate of at least 109×10^{12} horse power. Taking the radius of the earth's orbit to be 212 times the radius of the sun, the radiation of one square metre of the sun's surface is spread over 45,000 square metres of the earth's surface; therefore, the sun must radiate energy at the rate of at least 37,000 horse power per square metre of its surface 372

Comparison of the heat of the sun's rays with that produced by the combustion of liquid iron in oxygen . . . 373

Observations made during the solar eclipse.

Diagram of exposed surface of the sun at successive epochs after totality: Fig. 9 376

Table IV gives the rates of distillation observed at these epochs 377

Conclusion, containing remarks on the solar constant.

The experimental value found with the steam calorimeter at Sohag on 18th May 1882 was 0·89 gram-degree C. per square centimetre per minute, without making any correction whatsoever. It is certain that, using experimental means not inferior in efficiency to the steam calorimeter, heat can be obtained on the banks of the Nile from the sun at this rate.

The only physical constant used is the latent heat of steam, and this has been determined with the greatest exactness. Therefore, the principle on which the instrument is founded cannot be improved. The construction of the instrument was by the late Mr John Milne of the Milton House Works in Edinburgh, and no name in Great Britain could be a better guarantee of exact workmanship: but, independently of the reputation of the constructor, the instrument did in fact do the work with perfect efficiency. In order to save time in the construction, every part of the instrument which could be so made was made out of brass tube. Instrument-making is now so advanced that, with good will, there should be no difficulty in getting a steam calorimeter which, in competent hands, would give as good results as I got.

No. 11. SOLAR RADIATION. (From *Nature*, September 5, 1901, Vol. LXIV, p. 456; with postscript in 1911.) 383

Only an infinitesimal proportion of the total radiation reaches the earth. The remainder, in so far as we know, is wasted by dissipation into space 383

The amount of radiant heat which we can count on as being supplied to the whole earth in unit of time is the

PAGE

constant which is of greatest importance in terrestrial physics 384

When we have ascertained the supply of heat to the earth we have to inquire what becomes of it.

Fundamental principle :—The heat which the whole earth receives from the sun in the course of a year also leaves it in the course of a year.

The differential behaviour of the atmosphere to heat-rays striking and leaving the earth's surface is an example of Kirchoff's law that a body absorbs by preference the rays which it itself emits 385

Wind and all mechanical atmospheric effects are due to differences of density. These are produced not only by thermal expansion of the air, but also by mixture with it of a lighter gas ; such a gas is water-vapour 386

Description of methods of measuring the thermal effect of the sun's rays 387

Simultaneous observations made at the summit of Mont Blanc and at Chamonix 390

Observations on the Peak of Tenerife 392

Observations with the steam calorimeter in Egypt by the writer and by Mr Michie Smith at a height of 7000 feet above the sea at Kodaikanal in India. The highest rate of distillation observed by Mr M. Smith with the same instrument which I used in Egypt was 1·754 cubic centimetres per minute, whereas the highest realised in Egypt was 1·501 cubic centimetres. Therefore, at a height of 7000 feet above the sea one-seventh more heat can be collected, measured and used than was found possible on the banks of the Nile. But it is the amount which arrives at the sea-level, or near to it, that is alone of interest in the study of terrestrial physics 393

In a work entitled *Strahlung und Temperatur der Sonne* (1899) J. Scheiner sums up the discussion of this subject by giving 4 as the most probable value of the solar constant. This statement is disputed and it is shown that values of the solar constant of the order of 4 must be exaggerated.

No comment on these remarks was offered, but the later estimates of the solar constant began to fall. Attention is called to them in a Postscript written in February 1911 . . 395

Féry, who quotes 2·40 as the value of the solar constant generally accepted in 1909, arrives by his own experiments at the value 1·70, and he attributes the difference between these two values to excessive correction for the absorption by the atmosphere 396

PAGE

Conclusion:—Considering only my own observations, the final result of the experiments made with my steam calorimeter is that the calorific value of a sheaf of the sun's rays, having a section of one square metre, is at least 9698 gram-degrees Centigrade per minute at the terrestrial sea-level; and it is certain that heat can be obtained from them there at this rate and in a useful form by mechanical appliances of simple construction.

No. 12. THE TOTAL SOLAR ECLIPSE OF AUGUST 30, 1905. (From *Nature*, December 21, 1905, Vol. LXXIII, p. 173.) 399

As this eclipse was to be visible in an easily accessible part of Europe, where the probability of finding fine weather was great and the calculated duration of totality was nearly four minutes, I determined to see it. A considerable display of protuberances was expected and I wished to form my own idea of their size by personally checking their persistence or non-persistence through the phase of totality as seen from a station situated as nearly as possible on the line of mid-totality. The display of protuberances at the moment of second contact was very brilliant; when the time of mid-totality arrived not a trace of them was visible to the naked eye. Therefore these very brilliant protuberances had an apparent height less than 45 seconds of arc 400

This eclipse is compared with that of May 17, 1882, which was observed at Sohag on the Nile 401

No. 13. ECLIPSE PREDICTIONS. (From *Nature*, October 19, 1905, Vol. LXXII, p. 603.) 402

The predictions respecting the solar eclipse of August 30, 1905, as issued by the British *Nautical Almanac* and by the French *Connaissance des Temps* are compared, and their want of agreement is illustrated by a Table. The most striking discrepancy between the two predictions is shown by the width of the band of totality in Spain and the adjacent Mediterranean, which is given as from ten to eleven nautical miles greater by the French than by the British prediction . 403

The astronomical data on which these predictions were founded differed only in the accepted values of the apparent diameter of the moon, but the grounds on which the British and French authorities differed on this point have not been made public, so far as I know.

PAGE

No. 14. THE SOLAR ECLIPSE OF APRIL 17, 1912. (From *Nature*, May 9, 1912, Vol. LXXXIX, p. 241.) 404

This remarkable eclipse had a peculiar interest of its own, and the observers of it had the advantage that the central line passed through Paris and many other important places in Northern Europe, but up to the last moment it was uncertain whether the eclipse would be total, annular or partial. The value accepted for the apparent diameter of the moon was therefore of paramount importance. I observed it in front of the school house at Eaubonne, a northern suburb of Paris, and used an ordinary binocular when the naked eye was not enough, and a hand-screen made of three coloured glasses which reduced the density of the sun's light without altering its colour. This was a very efficient instrument and I am sorry that I do not know the source from which it was obtained. I bought it from a hawker in the streets of Barcelona, on the eve of the eclipse of August 30, 1905, and of course, like all hawker's goods, it was anonymous . . 405

I used it in front of the eye-pieces of the binocular and with it the diminution of the luminous crescent could be easily followed, and the view furnished was very sharp. As the area of the luminous crescent diminished rapidly before the advance of the dark lunar disc the colour of its light suddenly changed to a deep red. It would have been impossible to perceive the red colour, intense though it was, had it not been for the perfection of the hawker's reducing glass 407

After the light of the solar crescent had become red the lower cusp became indented by black blades or teeth ; then the upper cusp showed a similar phenomenon and almost in a moment the teeth spread irregularly over the whole crescent, crossing and intersecting each other like a crystallisation. Very quickly the dark disc of the moon advanced and pushed the beautiful network over the eastern edge of the sun, and apparently at the same moment the network reappeared, coming over the western edge of the sun, attached to the black limb of the moon and at the same time held by the limb of the sun. In a few moments the uncovered crescent of the sun had increased so much that the delicate lacework could no longer bear the tension, it parted and disappeared instantly, while at the same moment the dark limb of the moon recovered its perfect smoothness of outline. This was the form which "Baily's beads" took in this memorable eclipse. The pattern observed by Baily himself in 1835 was