measure at the earth's distance. Under these conditions a line from the sun to the earth will pass through the rift in the rings to the planet, and a terrestrial observer, suitably placed, may be able to view through the rift a portion of the planet's surface lit up by the sunlight. The effect will be that, of the arc of the Cassini division crossing the planet, a small portion will appear bright instead of dark, and may almost disappear ; as the albedo of Saturn is less than that of the adjacent portions of rings A and B, however, it is likely that there will be sufficient contrast to show the phenomenon.

There appears to be no record of any previous observation of this kind, and it will obviously be one of great delicacy and difficulty. As the exact limits of time and place are not absolutely determinable, it is hoped that the planet will be watched for some time before the date given.

CATALOGUE OF NORTH POLAR STARS.—Prof. Pickering has issued a catalogue of 589 stars in the vicinity of the North Pole as a separate part, No. 1., of vol. xlviii. of the *Annals of the Harvard College Observatory*. The measures are from enlargements made from the central portions of four negatives obtained with the 11-inch Draper telescope on November 29, 1887, February 23, 24 and March 10, 1897, with exposures of 60, 120, 120 and 101 minutes respectively. Full details are given of the reductions employed, and in consequence of the arrangements made at the Astrophotographic Congress of 1900, the positions are published in rectangular coordinates, which plan is to be adopted in general for future issues.

THERMAL EXPANSIONS AT LOW TEMPERATURES.[1]

THE apparent specific gravities of boiling liquid oxygen which resulted from weighing in the liquid a series of metals and other substances were given in a lecture entitled "New Researches on Liquid Air," printed in the Royal Institution *Proceedings* for 1896. For instance, silver, calc spar, rock crystal and iodide of silver gave the respective apparent densities 1·1278, 1·1352, 1·1316 and 1·1372. On correcting the weight of liquid displaced by each substance for contraction to − 182°·6—by calculating a Fizeau mean coefficient of expansion for the range of temperature employed, on the assumption that the parabolic formula might be legitimately extended to low temperatures—it was found that the real density of liquid oxygen so deduced for all the bodies used was, as a mean, 1·137.

The determination of the densities of substances at the temperature of the boiling point of oxygen—and hence of their mean coefficients of expansion between that temperature and ordinary temperatures—opens out a very large field of investigation, from which, if a sufficiently large number of observations were available, valuable deductions might be drawn. On account, however, of the expense and trouble of producing quantities of liquid oxygen, its use for this purpose is not likely to become general, although, when available, it is the easiest body to use in conducting such experiments, especially when the vacuum vessel containing it is immersed in a larger vessel containing the same fluid or well-evaporated air. The ease with which liquid air can now be obtained in many laboratories suggests that its application to work of this kind would in some cases be a convenience, and the present investigation was undertaken with the desire of ascertaining what accuracy could be attained, and how the method could be applied to inorganic or organic substances which occur in the form of fine crystals.

The use of a mixture of varying composition and density like liquid air necessitates a determination of its density with accuracy and rapidity before and during the course of the experiments. For this purpose, in the experiments about to be detailed, the liquid air that had been allowed to evaporate for twenty-four hours in advance was used in large silver-coated vacuum vessels of some 3 litres capacity. In order to ascertain the density of the liquid, a polished silver ball, which had been weighed once for all in liquid oxygen, was weighed in the sample of liquid air, and from the relative weights thus found the density of the liquid air could be approximately determined, assuming that of liquid oxygen to be 1·137.[2] To prevent any disturbing ebulli-

[1] "Coefficients of the Cubical Expansion of Ice, Hydrated Salts, Solid Carbonic Acid, and other Substances at Low Temperatures." By Prof. James Dewar, F.R.S. Abridged from a paper read before the Royal Society on May 1.
[2] As the correction due to the contraction of the silver ball between the temperature of boiling oxygen and that of the air sample is small, it may be neglected.

tion in the liquid-air flask in which the weighings took place, and to reduce the rate of its evaporation to a minimum during the course of an experiment, the substance to be used was previously cooled in a supplementary vessel containing liquid air and then transferred to the large flask. To avoid as far as possible the formation of cracks in the bodies during the process of immersion in the liquid air, it was found advisable to cool them slowly in the air of the vacuum flask first, and then to lower them into the liquid.

In this way, with proper care and attention, results were obtained comparable in accuracy with the density taken in liquid oxygen. Substances like solid carbonic acid and ice were weighed in the cool, gaseous air of the vacuum vessel, and their weights subsequently corrected for buoyancy. The temperature of the densest and lightest samples of liquid air was ascertained by the hydrogen thermometer, and that of the others deduced by graphic interpolation. As the entire range of temperature through which the bodies were cooled amounted to about 200°, a degree or two up or down has no real influence on the results ; the extreme range of temperature in the air samples was from 83°·8 to 86°·1 Abs.

When the body to be examined was a salt, it was employed in the form of a compressed block. One experiment was, however, made in a section of a large crystal of chrome alum. The salt, previously reduced to a fine powder, was moistened with water and compressed in a cylindrical steel mould under great hydraulic pressure. During compression the saturated salt solution drained away, and finally a cylindrical block of some 50 grammes of the salt was obtained free from porosity and hard enough to allow its surface to be polished. In this form salts and other materials similarly treated are especially adapted for accurate specific gravity determinations. After such treatment it was found that all the mechanically attached water was got rid of in the case of hydrated salts, and also in such as did not combine with water. In order to get cylindrical blocks of the salts showing no porosity, the presence of water, or rather the saturated salt solution, was found to be essential during the application of pressure. In the same way it was found to be an advantage in compressing such a substance as solid carbonic acid to moisten it with a fluid like ether before applying the hydraulic pressure.

Recalling the work of Playfair and Joule,[1] which originated in a suggestion of Dalton's that the volume of a hydrated salt in solution was simply the volume of the water of crystallisation, ice and some hydrated salts were selected, as well as some other bodies the coefficients of expansion of which they had determined. Substances of special interest were included in the list, like mercury, sulphur, iodine and solid carbonic acid, the latter being particularly important as an example of a solidified gas.

In the further conduct of an experiment, the observations made on a substance were three, namely, (*a*) the weight in grammes of the substance and suspending platinum wire, either in air of about 17° C. temperature or in the gaseous air in the flask containing the liquid air ; (*b*) the weight in grammes of the body and wire when immersed in the liquid air ; and (*c*) the weight in grammes of the suspending platinum wire in ordinary (17°) air.

In the case of substances of less density than liquid air, a polished copper ball weighing about 38 grammes was used as a sinker.

Two experiments were made on compressed cylinders of solid carbonic acid. In the first of these the carbonic acid was compressed dry, in the second, after a few drops of ether were added. The specific gravities of solid mercury, iodine and sulphur were also determined in liquid air. The iodine was in the form of a compressed cylinder, but the sulphur was a piece of a crystalline mass of native origin.

The specific gravity of the actual portion of the substance weighed in the liquid air was, with one or two exceptions, determined also at the temperature of the laboratory, about 17° C. From the two sets of observations, the value of the mean coefficient of cubical expansion between 17° C. and the temperature of liquid air was calculated.

In calculating coefficients of expansion, various forms may be given to the formula employed, and correspondingly different results may be obtained from the same set of observations. For short ranges of temperature these results are practically identical, but this no longer holds for a range of temperature such as we

[1] "Researches on Atomic Volume and Specific Gravity' (*Chem. Soc. Journ.*, vol. i., 121).

have in these experiments. All that is possible in the present instance is to adopt a linear formula. The usual formula is $v_T = v_0 (1 + \alpha T)$, where the value v_0 at 0° C. becomes v_T at T° C. when α is the coefficient of expansion. If we use densities (d) instead of volumes (v) this formula becomes

$$d_0 = d_T(1 + \alpha T), \qquad \text{or } \alpha = \frac{d_0 - d_T}{T d_T}; \qquad \alpha = 0\cdot000538.$$

Another formula, when T and T' are the temperatures dealt with, is

$$d_{T'} = d_T\{1 + \alpha(T' - T)\}, \text{ or } \alpha = \frac{d_T - d_{T'}}{(T' - T)d_{T'}}; \quad \alpha = 0\cdot000595.$$

Again

$$d_{T'} = d_T\{1 - \alpha(T' - T)\}, \text{ or } \alpha = \frac{d_T - d_{T'}}{(T' - T)d_T}; \quad \alpha = 0\cdot000558.$$

Also we may choose a mean formula

$$\alpha = \frac{d_T - d_{T'}}{(T' - T)\dfrac{d_T + d_{T'}}{2}}; \quad \alpha = 0\cdot000576.$$

The differences in the results of applying these formulæ are shown in the numerical values attached to each, which are calculated from the first experiment on solid carbonic acid, coupled with the specific gravity 1·53 of the solid at − 78° C.

Perhaps as a matter of general convenience, the first of these formulæ is the best; however, the second was chosen to conform with the old work of Playfair and Joule, and it is the results of this formula which are mentioned below.

The temperature range is taken from about − 186° C. to 17° C., unless otherwise stated.

Ice.—In determining the density at the temperature of liquid air of pieces of clear ice cut from large blocks, both the silver and copper balls already referred to were used as indicated. The true weight *in vacuo* of the silver ball was 132·2855 grammes, and that of the copper ball was 38·0802 grammes. The mean of the three densities obtained at − 188°·7 C. is 0·92999.

Recently Vincent (*Roy. Soc. Proc.*, 1901) has redetermined the density of artificial ice at the freezing point, and also its co-efficient of expansion. He finds the density to be 0·916, or from his tabulated results 0·91599. Playfair and Joule find the mean of the densities given by eight observers previous to them to be 0·919, and they themselves get 0·9184; Bunsen found it to be 0·9167. If we take this most recent determination, namely, 0·91599 at 0°, and 0·92999 at − 188°·7, and use the formula

$$d_0 = d_T(1 + \alpha T)$$

we get $\alpha = 0\cdot00008099$.

Vincent refers to "only one" estimate for natural ice, namely, 0·0001125, adding that "the mean of three available results for artificial ice is 0·000160"; finally, he gives the mean of four determinations of his own, namely, 0·000152. Apparently, then, we may take 0·0001551 as the mean coefficient of expansion of ice between 0° and (say) − 20° C. Thus the mean co-efficient of expansion between 0° and − 188° C. is about half of that between 0° and − 20° C. The mean coefficient of expansion of water in passing from 4° to − 10° is − 0·000362, and from 4° to 40° C. it is 0·0002155. Hence the mean coefficient of expansion of ice between 0° and − 188° C. is about one-fourth of that of water between 0° and − 10° C., and half of that between 4° and 100° C.

If we had the densities of ice at still lower temperatures, the values of the coefficient of expansion thence determined would, there is every reason to believe, be less than what we have found. We shall therefore not be overstraining the argument if we use the value just found to determine an upper limit to the density of ice at the absolute zero. The result is 0·9368, corresponding to a specific volume 1·0675. Now the lowest density of water, namely, at the boiling point, is 0·9586 (corresponding to specific volume 1·0432), so that ice can never be cooled low enough to reduce its volume to that of the liquid taken at any temperature under one atmosphere pressure. In other words, ice molecules can never be so closely packed by thermal contraction as the water molecules are in the liquid condition, or the volume of ice at the absolute zero is not the minimum volume of the water molecules. It has been observed by Prof. Poynting ("Change of State, Solid, Liquid," *Phil. Mag.* 1881) that if we supposed water could be cooled without freezing, then taking Brunner's

coefficient for ice, and Hallstrom's formula for the volume of water at temperatures below 4° C., it follows that ice and water would have the same specific volume at some temperature between − 120° and − 130°; applying the ordinary thermodynamic relation, then no change of state between ice and water could be brought about below this temperature. On the other hand, Clausius ("Mechanical Theory of Heat," p. 172, 1879) has shown that the latent heat of fusion of ice must be lowered with the temperature of fusion some 0·603 of a unit per degree. If such a decrement is assumed to be constant, then about − 130° the latent heat of fluidity must vanish.[1] Baynes discusses the same subject ("Lessons on Thermodynamics," p. 169, 1878) and arrives at the conclusion that at a temperature of − 122°·8 C. and under a pressure of 16,632 atmospheres there is no distinction between the solid and liquid forms of water. At temperatures below this limit, no amount of pressure would transform ice into water. We are thus relieved from a difficulty that would follow but for this demonstration of Clausius, namely, that the application of enormous pressures to ice, even at temperatures below that of liquid hydrogen, might cause the transformation of ice into water.

Carbonic Acid.—Two experiments were made with this substance, the masses in each case being about 20 grammes. These were compressed cylinders; the former was compressed dry, while the latter was slightly moistened with ether. The density at − 188°·8 C. was found to be 1·6308 and 1·6226.

The density of solid carbonic acid at its boiling point was formerly given as 1·5 (see *Proc. Roy. Inst.*, 1878, "The Liquefaction of Gases"), but the mean of my results at the time came to 1·53. Recently the same value has been found by Behn. Taking this value and 1·6267, the mean of the above results at − 188°·8 C., and using the formula

$$d_T = d_{T'}\{1 + \alpha(T' - T)\}$$

we get $\alpha = 0\cdot0005704$.

This is a very large coefficient of expansion, being greater than that of any substance recorded in the accompanying table, and comparable with that of sulphur between 80° and 100°, which, according to Kopp, is 0·00062. The coefficient of liquid carbonic acid at its melting point taken from the recent observations of Behn (*Chem. Soc. Journ.*, 1901) is 0·002989, so that the rate of expansion of the liquid at its smallest value is very nearly five times that of the solid.

Solid Mercury.—One experiment was made with solid mercury, and the result is given below.

Mallet determined with great accuracy the density of solid mercury at − 38°·85, his result being 14·193; coupling this with the density found for the liquid-air temperature, we find that the value of the coefficient of expansion between the melting point and − 189° C. is 0·0000887. For fluid mercury above 0° C. the mean value is about 0·000182, so that in the solid state this coefficient is about half of that in the fluid state.

The coefficients of expansion (α) obtained were as follows:—

	$\dfrac{\alpha}{0\cdot00}$
Sulphate of aluminium (18) [2]	0811
Biborate of soda (10)	1000
Chloride of calcium (6)	1191
Chloride of magnesium (6)	1072
Potash alum (24)	0813
Chrome alum (24), large crystal	0365
,, ,,	0478
Carbonate of soda (10)	1563
Phosphate of soda (12)	0787
Hyposulphate of soda (5)	0969
Ferrocyanide of potassium (3)	1195
Ferricyanide of potassium	2244
Nitro-prusside of sodium (4)	1138
Chloride of ammonium, sample i.	1820
,, ,, sample ii.	1893
Oxalic acid (2)	2643
Oxalate of methyl	3482
Paraffin	3567

[1] In my paper "On the Lowering of the Freezing-point of Water by Pressure" (*Roy. Soc. Proc.*, 1880), it was proved that up to 700 atmospheres the rate of fall was constant and equal to the theoretical value within the range of pressure if the difference between the specific volumes of ice and water remains constant; thence the latent heat of fusion must diminish just as Clausius had predicted.

[2] The figures in brackets refer to the number of molecules of water of crystallisation.

	α
	0·000
Naphthalin	3200
Chloral hydrate	1482
Urea	1579
Iodoform	2930
Iodine	2510
Sulphur	1152
Mercury	0887
Sodium	1865
Graphite (Cumberland)	0733

Sodium, extending down to low temperatures, has a coefficient about the same as that of mercury at the ordinary temperature. The coefficient for sulphur is about half of that between 0° and 100°, being 0·0002237, and that of iodine is not far removed from the value 0·000285 given for the solid at ordinary temperatures. The rate of expansion of liquid iodine is about three times this value. Paraffin ought to have a value of 0·0004633 from Fizeau, but Rodwell's coefficient between 0° and 38° is 0·00035. The value found for naphthalin is about half that of the liquid near its melting point, viz. 0·000785. If the liquid coefficient be taken at a corresponding temperature to that of the liquid carbonic acid when comparing it with the solid, then its value is 0·001213, or the coefficient would be now in the ratio of 4 to 1. The graphite calculated from Fizeau should be 0·0000929, which is greater than my value; but the samples were different. My two specimens of chloride of ammonium gave nearly the same value, and the result is in agreement with that found by Playfair and Joule, viz. 0·000191. If a Fizeau coefficient for this salt is calculated, the value is 0·0000761, which in this case is far too small. The coefficient found for oxalic acid is again only a little smaller than that given by Playfair and Joule, viz. 0·0002748. As regards the hydrated salts, phosphate of soda, hyposulphate of soda and chloride of calcium, having the respective values 0·0001384, 0·0001516 and 0·0006887, as found by Kopp, the low temperature coefficients are much smaller in each case. With the exception of carbonate of soda and chrome alum, all the other hydrated salts have a coefficient of expansion not differing greatly from that of ice at low temperatures. Generally, the densities of the compressed blocks of different bodies agreed well with the results of other observers, but my potash alum had only a density of 1·614, whereas Playfair and Joule give 1·731. It will be noted that iodoform is a highly expansive body like iodine, and that oxalate of methyl has nearly as great a coefficient as paraffin, which is one of the most expansive solids. The correcting factor was used for paraffin, naphthalin, chloral hydrate, iodoform and sodium.

It will be possible by cooling the moulds with liquid air during the process of hydraulic compression to produce cylindrical blocks of solid bodies of lower melting-points than any given in this investigation, such as alcohol, ether, nitrous oxide, ammonia, chlorine, &c., and to ascertain their coefficients of expansion in the solid state between the individual melting points and the boiling point of liquid air.

This method, which works well with liquid oxygen or air, fails when applied to liquid hydrogen, as the density of the liquid is too small (apart from other difficulties) to give accurate values for the weights of fluid displaced. For temperatures about 20° absolute, recourse must be had to measurements of the coefficient of linear expansion, and such observations could only be applied with ease to metallic bodies and alloys.

THE RISE OF THE EXPERIMENTAL SCIENCES IN OXFORD.[1]

IN the Middle Ages, the scholars swept in flocks, like migrating birds, from school to school. What we now call a University was then no particular spot on the earth; but, like the ark in the wilderness, moved whithersoever a great teacher, such as Fulbert, the Anselms, Abélard, Peter Lombard, unfurled his standard. This mobility was, indeed, a guarantee of the freedom and the power of learning.

The "Civitas Philosophorum," as Saint Thomas called Paris, was engaged in 1209 in burning all the works imputed to Aristotle. This attack "on the Lehrfreiheit" of Paris, when the culture of the first renascence was streaming into Europe from

the Arabian sources, drove its scholars abroad, and flights of them came to the comparatively unknown schools of Oxford and Cambridge. Oxford, already a centre of public affairs, sprang more suddenly than Cambridge into fame—on the scholastic side under the influence of the Friars Minors.

The Grey Friars, then breathing the humane spirit of their founder, stood for the people and for freedom, while the Friars Preachers were on the side of authority. Robert Grosseteste, who made Oxford as Abélard made Paris and Fulbert made Chartres, and his pupils, Adam Marsh and Roger Bacon, became Greek scholars of no inconsiderable attainment at a time when the potable gold of Greek tradition had virtually died out in the west, and with it the inspiration of natural knowledge. Adam Marsh, himself a Minor, was a statesman, a close friend of Simon of Montfort, and a champion of freedom of learning. Balliol was founded under Franciscan influences, and under this first temper in the next century, then in the teeth of the Minorites, Oxford was keenly Lollard; and with the suppression of Lollardism all intellectual life deserted her courts. Nevertheless, Oxford during the Middle Ages was a child of Paris rather than of Italy, whence Cambridge drew much of her nourishment, and was the picturesque stronghold of hierarchical traditions. Albert of Cologne, himself a Franciscan, vindicated against Paris the science of the Arab schools, and dignified the study of natural knowledge and experiment.

Pioneers of science may be divided into two kinds, into a group who, like Galileo, Boyle and Harvey, were themselves discoverers, and a second group, like Roger Bacon, Telesio, Patrizzi, Campanella, Francis Bacon, Ramus and Marsiglio, who did service rather as protestants and reformers of method. Whether Roger Bacon were more of a chemist than Albert of Cologne, or whether either got beyond the chemistry of Geber, whether Bacon advanced in optics, his special study, beyond Al Hazen, it is less important to ascertain than to declare that Bacon's title to fame is that he revived true methods of investigation. Many ancients had made experiments; Aristotle made many, Pliny made many; Bacon first declared that it was not experiment, but the experimental method, which was to regenerate science. We must not suppose that Roger Bacon was alone, as one crying in the desert; with the Arab illumination, natural science was in the air. Many voices, such as that of Peter of Méricourt, to whom Bacon regarded himself as indebted, preached experiment and contemned authority in natural research. The works of Nemorarius of Borgentreich, who first advanced from the statics of Greek and Arab to dynamics, were known to Bacon. The parabolic mirror and its focus were known to Al Hazen. Grosseteste had larger views than either Hales or Albert, and was no inconsiderable geometer. He wrote a treatise, "de Iride et de Cometis," and was a keen inquirer into the new sources of knowledge, including the "Res Physica," or medicine. Thomas Bungay, the eighth Provincial of the Friars Minors, was engaged with Bacon at Oxford in natural investigation, and, like other such inquirers, was regarded as a wizard. In Italy natural science continued, even in some abundance of life; but in Paris on the Isis, as in Paris on the Seine, its rudiments were soon buried under the Aristotelian and Galenical cenotaph by that busy gravedigger, Duns the Northumbrian, and were not dug up again until the day of Abbot Maurolycus and Vesalius nearly three centuries later. Thus one of the most piercing intellects and one of the most progressive societies our land has produced founded no school.

The great experimenters of the thirteenth as well as of the sixteenth and seventeenth centuries could hardly obtain skilled craftsmen for the construction of apparatus. Many observers, however, were themselves ingenious constructors—such as Archimedes, Hero, Leonardo, Brahé, Gilbert, Galileo, Huyghens, Hooke, Papin and, in our own time, Faraday and Ludwig. Roger Bacon, in his expenditure of money and labour upon machines, preceded Boyle and Hooke. We are not to suppose that Roger's machines were clumsy and rudimentary. The Alexandrian and Byzantine Greeks, and after them the Arabs, had constructed apparatus of surprising elaboration and ingenuity, and Bacon's machines would be well abreast of their time. In the sixteenth century, again, the reappearance of Greek preceded a new birth of natural science; although, unless at Wittemberg or Basel, freedom of speech was more closely stifled in Europe than in the time of Abélard, for Calvin himself bowed before Aristotle. William Solling, Linacre, Grocyn and Colet were therefore forerunners of the brilliant scientific revival of which, in the seventeenth century, the establishment