IV.

When a simple salt assumes one or more definite states of hydration at different temperatures below 100° C., the hydrated compounds A and B will be successively produced in the liquid state if a saturated solution of the original salt be heated to 100° C.; or, in other words, the chemical constitution of the liquid is altered so that, as higher temperatures are attained, it becomes a solution of substance A or of substance B, at intermediate temperatures mixtures of these.

V.

The action of heat on the violet hydrated compounds of chromium is not simply a dissociation of water-molecules or of acid from base, but a true decomposition, resulting in the production of a different class of salts with different generic properties.

Many new salts were prepared for this work, and others were examined with greater care than had previously been bestowed on them; from these substances, indeed, the most important part of the results were derived.

II. "On Attraction and Repulsion resulting from Radiation."—Part II. By William Crookes, F.R.S. &c. Received March 20, 1875.

(Abstract.)

This is the second part of a paper which the author sent to the Royal Society in August 1873. The author commences by describing improvements which he has made in the Sprengel pump, and in various accessories which are necessary when working at the highest rarefactions.

Continuing the description of apparatus, the author describes different new forms which enable the phenomena of repulsion by radiation to be observed and illustrated. A bulb 3 inches in diameter is blown at the end of a glass tube 18 inches long. In this bulb a fine glass stem, with a sphere or disk of pith &c. at each end, is suspended by means of a cocoon-fibre. The whole is attached to the Sprengel pump in such a way that it can be perfectly exhausted and then hermetically sealed. Besides pith, the terminals may be made of cork, ivory, metal, or other substance. During exhaustion several precautions have to be taken, which are fully entered into in the paper. To get the greatest delicacy in an apparatus of this kind, there is required large surface with a minimum of weight. An apparatus constructed with the proper precautions is so sensitive to heat, that a touch with the finger on a part of the globe near one extremity of the pith will drive the index round over 90°, whilst it follows a

piece of ice as a needle follows a magnet. With a large bulb, very well exhausted and containing a suspended bar of pith, a somewhat striking effect is produced when a lighted candle is placed about 2 inches from the globe. The pith bar commences to oscillate to and fro, the swing gradually increasing in amplitude until the dead centre is passed over, when several complete revolutions are made. The torsion of the suspending fibre now offers resistance to the revolutions, and the bar commences to turn in the opposite direction. This movement is kept up with great energy and regularity as long as the candle burns.

The author discusses the action of ice, or a cold substance, on the suspended index. Cold being simply negative heat, it is not at first sight obvious how it can produce the opposite effect to heat. The author, however, explains this by the law of exchanges, and shows that attraction by a cold body is really repulsion by radiation falling on the opposite side. According to the same law, it is not difficult to foresee what will be the action of two bodies, each free to move, if they are brought near to one another in space, and if they differ in temperature either from each other or from the limiting walls of the space. The author gives four typical cases, with experiments, which prove his reasoning to be correct.

Experiments are described with the object of ascertaining whether the attraction by heat, which, commencing at the neutral point, increases with the density of the enclosed air, will be continued in the same ratio if the apparatus is filled with air above the atmospheric pressure. This is found to be the case.

Various experiments are described with bulb-apparatus, in which the bulb is surrounded with a shell containing various adiathermous liquids and also with a shell of vacuum. In all cases radiation passed through, producing the normal action of attraction in air and repulsion in a vacuum.

The author next describes a form of apparatus by which measurable results are attainable. It consists of a long glass tube, with a wider piece at the end. In it is suspended a lump of magnesium by a very fine platinum wire, the distance between the point of suspension and the centre of gravity of the magnesium bob being 39·14 inches. Near the magnesium is a platinum spiral, capable of being ignited by a voltaic battery. Observations of the movement of the pendulum are made with a telescope with micrometer eyepiece. With this apparatus a large series of experiments are described, starting from air of normal density, and working at intermediate pressures up to the best attainable vacuum. The results are given in two tables.

With this apparatus it was found that a candle-flame brought within a few inches of the magnesium weight, or its image focused on the weight and alternately obscured and exposed by a piece of card at intervals of one second, will soon set the pendulum in vibration when the vacuum is

very good. A ray of sunlight allowed to fall once on the pendulum will immediately set it swinging.

The form of apparatus is next described which the author has finally adopted, as combining the greatest delicacy with facility of obtaining accurate observations, and therefore of getting quantitative as well as qualitative results. It consists of a glass apparatus in the shape of an inverted T, and containing a horizontal glass beam suspended by a very fine glass thread. At the extremities of the beam are attached the substances to be experimented on, and at the centre of the beam is a small mirror from which a ray of light is reflected on to a graduated scale. The advantage which a glass thread possesses over a cocoon-fibre is that the index always comes accurately back to zero. In order to keep the luminous index at zero, except when experiments are being tried, extreme precautions must be taken to keep all extraneous radiation from acting on the torsion-balance. The whole apparatus is closely packed all round with a layer of cotton-wool about 6 inches thick, and outside this is arranged a double row of Winchester quart bottles filled with water, spaces only being left for the radiation to fall on the balance and for the index ray of light to get to the mirror.

However much the results may vary when the vacuum is imperfect, with an apparatus of this kind they always agree among themselves when the residual gas is reduced to the minimum possible; and it is of no consequence what this residual gas is. Thus, starting with the apparatus full of various vapours and gases, such as air, carbonic acid, water, iodine, hydrogen, ammonia, &c., at the highest rarefaction, there is not found any difference in the results which can be traced to the residual gas. A hydrogen-vacuum appears the same as a water- or an iodine-vacuum.

With this apparatus the effect of exposing a torsion-balance to a continuous radiation is described, and the results are shown graphically. The effect of a short (11·3 seconds) exposure to radiation is next described, and the results are given in the form of a Table.

In another Table is given the results of experiments in which a constant source of radiation was allowed to act upon one end of the torsion-beam at a distance of 140 or 280 millims., various substances being interposed. The sensitiveness of this apparatus to heat-rays appears to be greater than that of an ordinary thermo-multiplier. Thus the obscure heat-rays from copper at 100°, passing through glass, produce a deflection on the scale of 3·25, whilst under the same circumstances no current is detected in the thermo-pile. The following substances are used as screens, and the deflections produced (when the source of radiation is magnesium wire, a standard candle, copper at 400°, and copper at 100°) are tabulated:—

Rock-salt, 20 millims. thick; rock-crystal, 42 millims. thick; dark smoky talc; plate glass of various thicknesses, both white and green; a

glass cell containing 8 millims. of water; a plate of alum 5 millims. thick; calc-spar, 27 millims. thick; ammonio-sulphate of copper, opaque to rays below F; ditto, opaque to rays below G.

The author considers that these experiments show that the repulsion is not entirely due to the rays usually called heat, *i. e.* to the extreme and ultra red of the spectrum. Experiments have been tried with the electric and the solar spectrum formed with a quartz train, which prove the action to be also exerted by the luminous and ultra violet rays. Some numerical data have been obtained; but unfavourable weather has prevented many observations being made with the solar spectrum.

The barometric position of the neutral point dividing attraction from repulsion is next discussed. The position of this point varies with the density of the substance on which radiation falls, the ratio of its mass to its surface, its radiating and conducting-power for heat, the physical condition of its surface, the kind of gas filling the apparatus, the intensity of radiation, and the temperature of the surrounding atmosphere. The author is inclined to believe that the true action of radiation is repulsion at any pressure, and that the attraction observed when the rarefaction is below the neutral point is caused by some modifying circumstances connected with the surrounding gas, but not being of the nature of air-currents.

The neutral point for a thin surface of pith being low, and that for a moderately thick piece of platinum being high, it follows that at a rarefaction intermediate between these two points pith will be repelled, and that platinum will be attracted by the same beam of radiation. This is proved experimentally; and an apparatus showing simultaneous attraction and repulsion by the same ray of light is described and illustrated in the paper.

The paper concludes with a discussion of the various theories which have been adduced in explanation of these phenomena. The air-current and electrical theory are considered to have been abundantly disproved. The following experiment is given by the author to show that Prof. Osborne Reynolds's hypothesis of the movements due to evaporation and condensation at the surface will not account for all the facts of the case, and that therefore he has not hit upon the true explanation. A thick and strong bulb was blown at the end of a piece of very difficultly fusible green glass, specially made for steam-boiler gauges. In it was supported a thin bar of aluminium at the end of a long platinum wire. The upper end of the wire was passed through the top of the tube and well sealed in, for electrical purposes. The apparatus was sealed by fusion to the Sprengel pump, and exhaustion was kept going on for two days, until an induction-spark refused to pass across the vacuum. During this time the bulb and its contents were several times raised to a dull red heat. At the end of two days' exhaustion the tube was found to behave in the same manner as, but in a stronger degree than, it would in a less

perfectly exhausted apparatus, viz. it was repelled by heat of low intensity and attracted by cold. A similar experiment was next tried, only water was placed in the bulb before exhaustion. The water was then boiled away *in vacuo*, and the exhaustion continued, with frequent heating of the apparatus to dull redness, for about 48 hours. At the end of this time the bar of aluminium was found to behave exactly the same as the one in the former experiment, being repelled by radiation.

It is impossible to conceive that in these experiments sufficient condensable gas or vapour was present to produce the effects Prof. Osborne Reynolds ascribes to it. After the repeated heating to redness at the highest attainable exhaustion, it is impossible that sufficient vapour or gas should condense on the movable index to be instantly driven off by the warmth of the finger with recoil enough to drive backwards a heavy piece of metal.

While objecting to the theories already advanced as not accounting for all the facts of the case, the author confesses that he is not as yet prepared with one to put in their place. He wishes to avoid giving any theory on the subject until a sufficient number of facts have been accumulated. The facts will then tell their own tale. The conditions under which they invariably occur will give the laws, and the theory will follow without much difficulty.

Supplement. Received April 20, 1875.

Since the experiments mentioned in the foregoing Abstract were concluded, the author has examined more fully the action of radiation on black and white surfaces. At the highest exhaustion heat appears to act almost equally on white and on lampblacked pith, repelling them in about the same degree.

The action of the luminous rays, however, is different. These repel the black surface more energetically than they do the white surface. Taking advantage of this fact, the author has constructed an instrument which he calls a radiometer. This consists of four arms, suspended on a steel point resting on a cup, so that it is capable of revolving horizontally. To the extremity of each arm is fastened a thin disk of pith, lampblacked on one side, the black surfaces facing the same way. The whole is enclosed in a glass globe, which is then exhausted to the highest attainable point and hermetically sealed.

The author finds that this instrument revolves under the influence of radiation, the rapidity of revolution being in proportion to the intensity of the incident rays.

Several radiometers, of various constructions as regards details, but all depending on the above-named discovery, were exhibited by the author at the Soirée of the Royal Society on the 7th inst., and numerous experiments

were shown with them. The following Table, which gives the result of some experiments tried with one of the first-made radiometers (and therefore not so sensitive as more recent instruments), is copied from a card which was distributed during the evening:—

"Time required for One Revolution.

"Source of radiation.	Time in seconds.
"1 candle, 20 inches off	182
„ 10 „	45
„ 5 „	11
2 candles, 5 „	5
4 „ 5 „	3
8 „ 5 „	1·6
1 candle, 5 „ behind green glass ..	40
„ 5 „ „ blue „ ..	38
„ 5 „ „ purple „ ..	28
„ 5 „ „ orange „ ..	26
„ 5 „ „ yellow „ ..	21
„ 5 „ „ light red „ ..	20
Diffused daylight, dull	2·3
„ „ bright	1·7
Full sunshine, 10 A.M.	0·3
„ „ 2 P.M.	0·25"

These experiments are not mentioned in the paper of which the above is an abstract, as it is intended to make the radiometer the subject of a future communication to the Society.

Mr. Lockyer communicated some particulars of the Eclipse of the Sun, April 6th, as observed at Bangkok, Siam.

April 29, 1875.

The DUKE OF DEVONSHIRE, K.G., Vice-President, in the Chair.

The Right Hon. W. E. Forster and the Right Hon. Russell Gurney were admitted into the Society.

The Right Hon. Sir James Colville, whose certificate had been suspended, as prescribed by the Statutes, was balloted for and elected a Fellow of the Society.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—