It may be well to mention a few of the more striking facts noted when the spectra are photographed with an instrument of high dispersion. Ordinarily, perhaps half the lines are doublets of about 1 cm^{-1} separation, but if the crystals are under strain many more lines resolve and the separation becomes greater. This splitting may be attributed to the action of the electric fields in the crystal on the basic level. Professor Kramers[4d] has suggested that the ^8S level should dissolve into four slightly separated levels. These, with the rules of selection which are applicable, should give separations of the sort observed. Just as was anticipated, the spectrum of a triclinic crystal photographed by Mr. G. C. Nutting and me shows the dissolution into pairs to be much more pronounced, with several of the lines which apparently were single in the monoclinic $GdCl_3 \cdot 6H_2O$ resolved clearly into doublets. In a magnetic field the double lines split into several components, usually five or more, and in most instances it seems that still more components would appear under higher dispersion. As a usual thing the lines tend to separate into two groups of components which, under low dispersion, show as doublets of the sort reported by J. Becquerel, and Freed and Spedding.

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High Velocity Vapor Jets at Cathodes of Vacuum Arcs

From measurements of the force of recoil on the cathode of an arc drawn in a high vacuum, and from measurements of the amount of cathode material which was lost, Tanberg[1] has calculated the mean velocity of the material leaving the cathode to be the extraordinarily high one of over 10^6 cm per sec. K. T. Compton[2] has proposed a theory of the development of high molecular velocities, but explains that, "... this criticism does not alter Mr. Tanberg's basic conclusion regarding a high speed neutral vapor stream. It merely suggests an electrical mechanism for the acquiring of these speeds instead of assuming a terrifically high temperature at the cathode."

Close scrutiny of Dr. Compton's suggestion that high velocity neutral molecules leave the cathode as a result of the existence of an accommodation coefficient for the positive ions neutralized at the cathode, indicates, however, that the velocity of these molecules cannot be nearly as great as the velocity obtained by Tanberg. The maximum velocity of the neutralized ions cannot be expected to be much greater than that corresponding to the cathode drop, whereas Tanberg observed velocities of an order corresponding to 70 volts. Hence, if the reaction of the neutralized positive ions is to account for the force upon the cathode observed by Tanberg, the stream of neutralized positive ions leaving the cathode with part of their original energy must be of much greater density than the high velocity stream calculated by Tanberg. In fact, Compton, by assuming that all the positive ions participate in the reaction, calculates that the average energy of the neutralized ions need be less than 0.4 volt to give the force measured by Tanberg.

The high speed stream of Tanberg must still be assumed to leave the cathode *region*, even though the mechanism proposed by Compton may possibly account for the way in which force is communicated to the cathode itself. Because of the high vacuum, the only material leaving the cathode region is substantially only the material lost from the cathode, which Tanberg weighed. The force on the cathode must equal the momentum of the material leaving the cathode *region*, regardless of whether this material acquires its velocity at the cathode surface or elsewhere in the region.

The argument for the necessary existence of Tanberg's high speed stream seems to be valid unless there is a high density of gas in the vessel in which the experiment is carried out. In such a case, the lower speed neutralized positive ions of Dr. Compton could communicate their momentum to many gas molecules, without any of them acquiring a high velocity. But a high gas pressure in the tube during the period of arcing does not seem likely. To obtain a high density of copper vapor throughout the vessel would require almost complete reflection of copper atoms at the walls of the vessel, a condition which does not seem very probable for heavy metal atoms. If such complete reflection did occur, one would expect to have a uniform deposit of copper on all parts

[1] Tanberg, Phys. Rev. **35**, 1080 (1930).
[2] K. T. Compton, Phys. Rev. **36**, 706 (1930).

of the containing vessel. Actually, however, experiment shows that the deposit is most dense directly opposite the cathode spot, with practically no deposit behind the cathode, the distribution of density following a cosine law roughly. So, little reflection must occur, condensation must take place on first impact, and vapor must flow from the cathode region at a rate just equal to the rate of vaporization measured by Tanberg. Since the momentum measured by Tanberg is carried by the mass he used, the velocity he calculated must be correct.

In the same way, the calculated high velocity of vapor striking a vane 2 cm from the cathode can be in serious error only if considerable reflection from the vane occurred,—a condition which does not seem to be true. Thus, if the force on the cathode is due to the reaction of neutralized ions, as proposed by Compton, some mechanism must exist whereby the many neutralized ions of low velocity transfer their momentum to the few atoms leaving the cathode region, with consequent high velocity.

The cathode spot itself, on the metal, need not be, and probably is not, at a high temperature. The experiment merely shows that a very high velocity vapor stream issues from the cathode region. A similarly high reaction upon the cathode of the mercury arc has been observed recently by Kobel.[3]

Whether or not to ascribe a high temperature to such a high velocity vapor stream is merely a matter of use of words. Perhaps, for the sake of emphasizing the unusual magnitude of the velocity, one may speak of the temperature of the vapor jet through the relation $3kT/2 = mv^2/2$.

Experiments to measure the magnitude of the vapor jet velocity by an independent means are in progress in this laboratory.

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February 25, 1931.

[3] Kobel, Phys. Rev. **36**, 1636 (1930).

Knowledge of Past and Future in Quantum Mechanics

It is well known that the principles of quantum mechanics limit the possibilities of exact prediction as to the future path of a particle. It has sometimes been supposed, nevertheless, that the quantum mechanics would permit an exact description of the past path of a particle.

The purpose of the present note is to discuss a simple ideal experiment which shows that the possibility of describing the past path of one particle would lead to predictions as to the future behaviour of a second particle of a kind not allowed in the quantum mechanics. It will hence be concluded that the principles of quantum mechanics actually involve an uncertainty in the description of past events which is analogous to the uncertainty in the prediction of future events. And it will be shown for the case in hand, that this uncertainty in the description of the past arises from a limitation of the knowledge that can be obtained by measurement of momentum.

Consider a small box B, as shown in the figure, containing a number of identical particles in thermal agitation, and provided with two small openings which are closed by the shutter S. The shutter is arranged to open automatically for a short time and then close again, and the number of particles in the box is so chosen that cases arise in which one par-

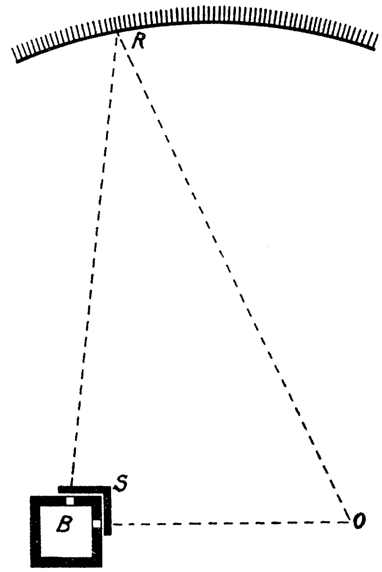

Fig. 1.

ticle leaves the box and travels over the direct path SO to an observer at O, and a second