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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[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-

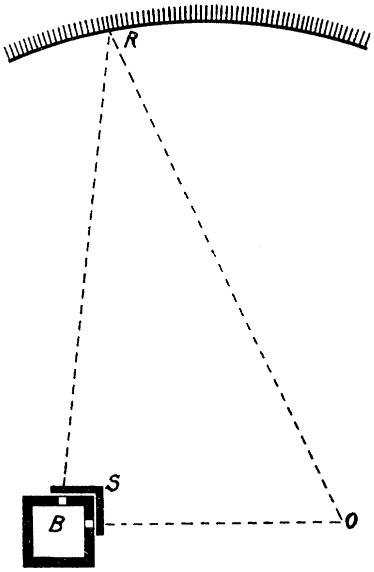

Fig. 1.

ticle leaves the box and travels over the direct path SO to an observer at O, and a second particle travels over the longer path *SRO* through elastic reflection at the ellipsoidal reflector *R*.

The box is accurately weighed before and after the shutter has opened in order to determine the total energy of the particles which have left, and the observer at *O* is provided with means for observing the arrival of particles, a clock for measuring their time of arrival, and some apparatus for measuring momentum. Furthermore the distances *SO* and *SRO* are accurately measured beforehand, —the distance *SO* being sufficient so that the rate of the clock at *O* is not disturbed by the gravitational effects involved in weighing the box, and the distance *SRO* being very long in order to permit an accurate reweighing of the box before the arrival of the second particle.

Let us now suppose that the observer at *O* measures the momentum of the first particle as it approaches along the path *SO*, and then measures its time of arrival. Of course the latter observation, made for example with the help of gamma-ray illumination, will change the momentum in an unknown manner. Nevertheless, knowing the momentum of the particle in the past, and hence also its past velocity and energy, it would seem possible to calculate the time when the shutter must have been open from the known time of arrival of the first particle, and to calculate the energy and velocity of the second particle from the known loss in the energy content of the box when the shutter opened. It would then seem possible to predict beforehand both the energy and the time of arrival of the second particle, a paradoxical result since energy and time are quantities which do not commute in quantum mechanics.

The explanation of the apparent paradox must lie in the circumstance that the past motion of the first particle cannot be accurately determined as was assumed. Indeed, we are forced to conclude that there can be no method for measuring the momentum of a particle without changing its value. For example, an analysis of the method of observing the Doppler effect in the reflected infrared light from an approaching particle shows that, although it permits a determination of the momentum of the particle both before and after collision with the light quantum used, it leaves an uncertainty as to the time at which the collision with the quantum takes place. Thus in our example, although the velocity of the first particle could be determined both before and after interaction with the infrared light, it would not be possible to determine the exact position along the path *SO* at which the change in velocity occurred as would be necessary to obtain the exact time at which the shutter was open.

It is hence to be concluded that the principles of the quantum mechanics must involve an uncertainty in the description of past events which is analogous to the uncertainty in the prediction of future events. It is also to be noted that although it is possible to measure the momentum of a particle and follow this with a measurement of position, this will not give sufficient information for a complete reconstruction of its past path, since it has been shown that there can be no method for measuring the momentum of a particle without changing its value. Finally, it is of special interest to emphasize the remarkable conclusion that the principles of quantum mechanics would actually impose limitations on the localization in time of a macroscopic phenomenon such as the opening and closing of a shutter.

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Deviations from Kerr's Law at High Field Strengths in Polar Liquids

When an electric field is established in some substances they become doubly refracting with their "optic axes" in a direction parallel to the lines of force. This phenomenon was discovered by Kerr[1] and is known as the Kerr electro-optical effect. Kerr and others[2] have shown that if n_1 and n_2 are the refractive indices for the components of the light vibration parallel and perpendicular, respectively, to the lines of force, then their phase difference after passing through the electric field is

$$D=\frac{2\pi l({}_1n-n_2)}{\lambda}=2\pi BlE^2$$

where λ is the wave-length of the light, l is the length of the light path through the electric field whose magnitude is E. B is Kerr's constant, but has been found to vary with different substances, wave-lengths and tempera-

[1] Kerr, Phil. Mag. (4) **50**, 337, 446, (1875).

[2] See G. Szivessy, Handbuch der Physik, 724–808, 21, 1929.