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.

ALBERT EINSTEIN
RICHARD C. TOLMAN
BORIS PODOLSKY
California Institute of Technology,
February 26, 1931.

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.

tures. In the present work a method has been devised for testing the possible dependence of B upon the magnitude of E. The well-known theories[3,4] show to a sufficient degree of approximation that

$$B \propto \frac{(n_0^2-1)(n_0^2+2)(K+2)^2}{n_0 T}\left((1+\phi\frac{\mu^2}{T}\right)$$

where n_0 is the index of refraction, K is the dielectric constant, T the absolute temperature and μ the electric moment of the molecule. It has been shown that in polar substances the dielectric constant varies with the strength of the applied electric field, and has been explained as due to an electrical saturation.[5] Therefore in polar liquids B might be expected to decrease with increasing E.

In the present experimental arrangement light from an incandescent filament, made parallel by a lens, plane-polarized by a nicol prism, passed through a Kerr cell 5 cm in length and 3 mm spacing between the plates, then through a second Kerr cell 25 cm in length with a 3 mm spacing between the plates and finally through a second nicol prism crossed with respect to the first. The plane of polarization of the light made an angle of 45° with the lines of force in the first Kerr cell while the plane of the plates of the second cell was 90° from that of the first. A high voltage d.c. potential was applied directly across the first Kerr cell and a variable running tap-water resistance. The second Kerr cell was attached in parallel with just enough of the resistance so that the double refraction in the first Kerr cell was exactly compensated by that in the longer second Kerr cell. The electric field in the first cell was therefore more than twice that in the second. The potential across the first cell and the resistance was then, for example, changed from 30,000 volts per cm to 60,000 volts per cm, so that any change in B with increasing E would appear as a lack of compensation of the light. In the case of CS_2 which is non-polar, practically no light was observed to pass the second nicol prism, that is, the double refraction in the first cell continued to be compensated by that in the second within the limits of precision. However, in the case of carefully distilled chloroform, which is polar, it was found necessary to lower the potential across the second Kerr cell (many times the least amount detectable) in order to make the two cells compensate each other or, again, to reduce the intensity of the light passing the second nicol to zero. This shows that for chloroform B decreases with increasing electrical field. Since the amount of light passing an arrangement of the kind here described is $I=I_0 \sin^2 D/2$ the method is very sensitive to small variations in Kerr's law and gives a simple and precise way of studying electrical saturation effects. The method is being improved and refined in order to make a study of both liquids and gases. A detailed description of the method and a discussion of the results will appear later.

J. W. BEAMS

University of Virginia,
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[3] See Debye, Marx Handbuch der Radiologie, **5**, 754–776, (1924).

[4] Raman and Krishman, Phil. Mag. **3**, 724–735, (1927).

[5] See Debye, Polar Molecules, Chem. Catalog Co., 109, (1929).