of these laws, which is responsible for their abstractness, and their flexibility, as evinced in a concrete manner by the uncertainty principle, make for their adaptability to other domains of thought. One might expect that this generality and plasticity would be characteristic of fundamental laws of nature. Viewed in this light one need not make apologies for nature by attributing the indeterminateness in its laws to the limitation of our knowledge imposed on us by the very act of observation.* Although if one feels that somehow our fallibility does play a part in our picture of the universe, one might view the objective laws of quantum mechanics as bringing before us the subjective aspect of definition and concept. As for the uncertainty principle, one can, following Darwin (Proc. Royal Soc. **A130,** 1931), regard it in the same role as the part played by the clocks and rods in the early formulation of the relativity theory when it was necessary to supplement the formal theory by concrete examples showing how the old classical ideas failed in specific cases. The general laws of the quantum mechanics, which are at the bottom of the uncertainty principle, are not conditioned by a theoretical clumsiness in our means of observation.

The intimate connection between the indeterminateness in quantum mechanics and the concept of observation may be due to the fact that "observation" implies structure. We could not plan our experiments but with the supposition that the elementary entities of nature have a structure. But the elementary entities of nature have neither a particle nor a wave basis. It is only after quantization—after observation—that one can legitimately introduce space and time. The Schroedinger equation may be looked upon as controlling, in a statistical way, the space-time manifestations of the elementary entities of nature, although the equation itself is devoid of any geometrical interpretation. We make manifest the indeterminateness in nature by bringing over space-time concepts and space-time description to atomic theories that, in order to predict, must go beyond observation. If a scientific theory were humbled to be valid only as far as observation goes, what would happen to cosmogony and geophysics? Should one doubt the validity of scientific inference because it yields results that can not be expressed in terms of familiar things, that are beyond the range of our sensations? There are good reasons for believing that quantum laws are not laws which man's mind has imposed on nature but are laws which nature is having a rather difficult time imposing on man's mind.

Finally, if one does not try to elevate his preconceived ideas and intuitions about causality to a law of nature, but merely views causality as the assumption that nature can be comprehended, can be grasped in thought—though not in imagery—there is no failure of causality in quantum mechanics.

ALEXANDER W. STERN

Brooklyn, N. Y.,
April 11, 1931.

* Prof. J. E. Turner (Nature **126,** pp. 995) views the indeterminism in quantum mechanics as having nothing to do with causation but interprets "not determined" to mean "not ascertained." Other physicists argue that the uncertainty principle does not exclude exact laws from physics but means merely that we have no way of verifying them.

On the Effect of Resonance in the Exchange of Excitation Energy

It is well known that exchange of excitation energy between atoms on collision takes place most readily if the "resonance" between the two atoms is good, i.e. if the quantum states of the two atoms are such that the excitation energy of one nearly matches the excitation energy of the other, so that only a small change in the relative kinetic energy of the two atoms is necessary in order to effect the energy balance before and after the collision.

This point has been discussed by Kallmann and London (Zeits. f. physik. Chem. **2B,** 207 1929)) who came to the conclusion that the cross-section would in general be larger the better the resonance. Their calculation is very interesting but not entirely free from objections. It may, therefore, not be out of place to look at the matter from another point of view, perhaps itself open to some objections, but which I believe brings out the nature of the problem very clearly.

The Franck-Condon principle, which says that those transitions are most probable which disturb the motion of the nuclei the least, has been very successful in accounting for the intensities in band spectra, and it has also been applied recently to the case of predissociation (Franck and Sponer, Göttingen Nach., 1928, 241; Herzberg, Zeits. f. Physik **61,** 604 (1930); Turner, Bull. Am. Phys. Soc. **6,** 16 (1931)). Now in the case under consideration we can treat the pair of atoms which exchange energy as an unstable molecule, draw potential energy curves for the electronic states of the "molecule," (similar to London, Zeits. f. physik. Chem. **11B,** 222 (1930)) and handle the transitions from one continuum to another in the same way that we treat, in the predissociation case, transitions which take place from a discrete state to a continuum. It may be well to point out, parenthetically, that the case of predissociation and the present case are really quite different from the case of adsorption or emission of radiation, and, naturally, the real justification of this use of the Franck-Condon rule will come when the matter has been given a more or less rigorous quantum mechanical investigation.

In Fig. 1 let curve 1 be the potential energy curve (potential energy $= U$, distance between atoms $= r$) with atom A excited, atom B unexcited, and let curve 2 be the curve with atom B excited, A unexcited. Suppose curve 1 represents the initial state of the pair of atoms. Then its intersection with a horizontal line gives the distance of closest approach of the atoms if they make a head-on collision with the energy indicated by the horizontal line. If curve 1, curve 2, and the horizontal line intersect at the same point, as shown, or somewhat near the same point, then, according to the Frank-Condon theory, we may expect a relatively large probability of transition provided, of course, the interaction between the atoms at this distance, r, is great enough. If the two atoms do not collide head on, this means that they have a relative angular momentum, and we can represent the situation by adding a term $(h^2/8\pi^2M)\,j(j+1)/r^2$ to the potential energy, where M is the reduced mass, and j the rotational quantum number; but as a more or less rigorous selection rule for j will hold, practically the same amount must be added to the curve for the final state: they will therefore continue to intersect at the same value of r. Thus all collisions with this distance of approach will be favored. Collisions with something near this distance of approach will be somewhat less favored, and there will be a spherical shell in which favorable collision take place. Now it is seen that the closer together the asymptotic values of U_1, and U_2, in general the greater the distance r at which they will intersect, and hence, we may infer, the greater the size of the spherical shell in which collisions are favored by the particular factor under consideration. It may not be the only factor, and it certainly cannot stretch the region of favorable collisions out indefinitely, but all the indications from analogous cases are that it should be an important factor. The case where the asymptotic values of U_1 and U_2 coincide is just the case of exact resonance, and it is easy to see why transitions with exact resonance should be favored, but it is seen that the precise definition of good resonance is involved in complications which must be treated specially in any given case.

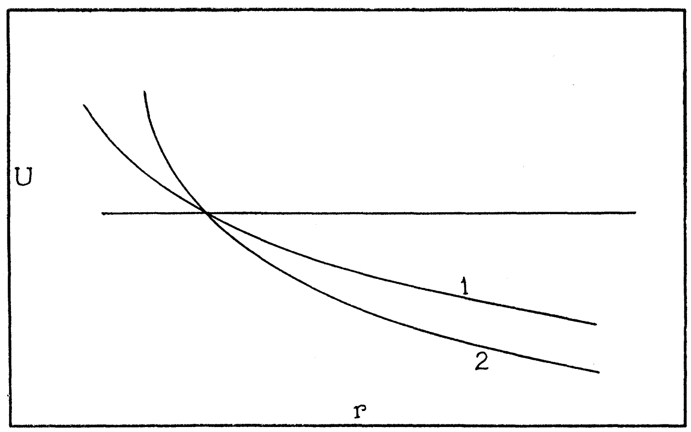

Fig. 1.

Of course, we cannot draw definite conclusions from such qualitative observations, but they at least provide a guide for future quantitative calculations. For the most part the applications of the Franck-Condon principle are just as qualitative as this one, but in the case of band spectra they have provided the stimulus for some successful quantitative work.

I have recently extended the quantitative work described in a preliminary note (Proc. Nat. Acad. Sci. **17,** 34 (1931)), where the force which acts between the two atoms is supposed to be due to their momentary dipole moments, by treating the two atoms as a molecule and using perturbations of the type introduced by Slater, (Proc. Nat. Acad. Sci. **13,** 423 (1927)). It appears, though with some assumptions I am trying to remove, that practically no transitions will take place unless the resonance is extremely good; the potential energy curves in this case do not intersect. Yet, experimentally, cross-sections very much larger than normal, or cross-sections unusually large for the type of transition considered, occur for such great resonance differences as 40 to 60 millivolts. I am inclined to think that other forces than the interaction forces of dipoles come into play, even when the radius of action is very large. Kallmann and London, themselves, noted that large cross sections would be expected when electron orbits are large.

It may be well to mention here that Eq. (5) of my preliminary article mentioned above, is incorrect. This error, which was carried through, should not make much difference in the final results and will be corrected later.

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Chemical Laboratory,
Harvard University,
April 11, 1931.

The Formation of Striae in a Kundt's Tube

For the past seven years the author has been experimenting on striae formed in a Kundt's tube to determine, if possible, the cause of such striae. An article concerning the use of pith dust in a Kundt's tube was published by the author in Nature **118,** 157 (1926). In July 1929 he was able to show conclusively that a rotation of the dust particles on each side of a striation takes place; Phys. Rev. **36,** 1098 (1930); Science **72,** 442 (1930). January 14, 1931 the author made motion pictures of these rotations which take place on each side of each single striation. Fig. 1 shows an enlarged photograph of one such striation made from the motion picture negative. The black particles composing the striae were cork-charcoal. The striae were produced in a glass tube in which the air was compressed and rarefied by means of a metal piston attached to one prong of an electrically-driven tuning fork. Fig. 2 is a diagram showing the direction of the rotations taking place on each side of a single striation. Further details are given in the references above cited.

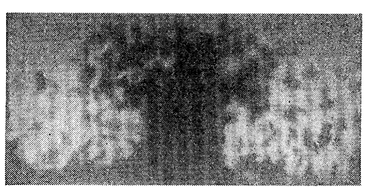

Fig. 1.

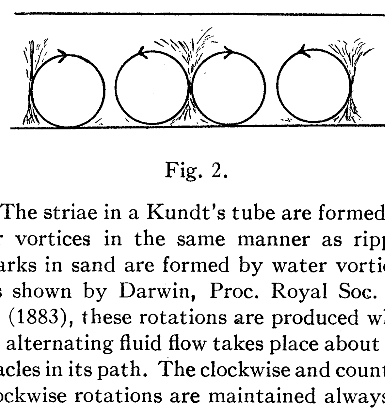

Fig. 2.

The striae in a Kundt's tube are formed by air vortices in the same manner as ripple-marks in sand are formed by water vortices. As shown by Darwin, Proc. Royal Soc. **36,** 18 (1883), these rotations are produced when an alternating fluid flow takes place about obstacles in its path. The clockwise and counter-clockwise rotations are maintained always in the same direction regardless of the fact that the fluid stream is alternating.

Also the author has shown that, when using cork particles of the same size, as the frequency of vibration of the air column in the tube increases, the average distance between striae becomes smaller. The photographs of Fig. 3 illustrate this fact. Also the author has shown that, with a constant frequency of vibration of the air in the tube, as the cork particle size is made smaller, the distance between adjacent striae becomes less. The photographs in Fig. 4 illustrate this fact.