namics alone it is impossible to obtain even an estimate of the absolute magnitude of a reaction velocity. This apparent weakness, due to the very nature of thermodynamics, is actually a power, since it enables us to establish theorems on reaction rates which are independent of the magnitude of these rates and of the intimate reaction mechanisms. The situation is indeed quite similar with most of the other physical or chemical quantities with which thermodynamics is concerned.

A particularly simple and fruitful way of expressing the criterion for irreversible changes given by the second law of thermodynamics is to state that in the case of one single irreversible reaction, the product of affinity and reaction velocity is necessarily positive[1]:

$$A\,v > 0 \qquad (1)$$

The velocity v is the time derivative of the degree of advancement of the reaction, the affinity A is defined, for instance, as minus the partial derivative of the free energy or thermodynamic potential with respect to this degree of advancement, pressure and temperature being constant. If two independent reactions occur simultaneously in the system, the second law requires

$$A_1 v_1 + A_2 v_2 > 0 \qquad (2)$$

Two reactions are independent when, representing them by ordinary chemical formulas, it is impossible to derive one from the other by some rearrangement. Several reactions are independent when none of them can be derived from the others by means of a linear combination. Suppose now that, for some particular state of the system, we have $A_2 > 0$, $v_2 > 0$, $A_1 < 0$.

It follows from (2) that

$$v_1 < -\frac{A_2}{A_1} v_2 \qquad (3)$$

(Division by $A_1 < 0$ requires the change in the sign of the inequality). This upper limit of v_1 is positive, which shows that reaction 1 may occur in its unnatural direction. In other words, coupling of reaction 1 by reaction 2 is thermodynamically possible. The velocity of the coupled reaction must, however, remain inferior to a certain definite limit. We should add that the equality sign is also allowed in formula (3). We consider this very simple theorem as a typical piece of thermodynamic information concerning reaction rates.

Coupled or reversed reactions in biological systems have been observed and discussed by Borsook[2] and other authors. We hope that rate measurements will at some time or other be made on such systems and that our formula (3) will then be directly verified. We would also be interested in discovering a clear-cut case of coupling in some non-biological system.

A more detailed study of the thermodynamics of coupled reactions has been published elsewhere.[3]

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MAGNIFICATION OF TIME AS A RESEARCH TECHNIQUE IN THE STUDY OF BEHAVIOR

THE magnification or condensation of *space* by means of a microscope or telescope and the magnification or condensation of *energy* through thousands of mechanical and electrical devices are established scientific methods which we take for granted. It seems peculiar that the magnification or condensation of *time* has so infrequently entered into scientific concept and methodology, particularly since the means of such time magnification or condensation have been at hand and used for twenty or thirty years. We refer to ultra-rapid and infra-slow motion picture photography.

Ultra-rapid motion picture photography usually refers to pictures taken at approximately 64 exposures per second and subsequently projected at 16 to 20 exposures per second, thus affording a time magnification of four. Until recently comparatively little work has been done above this speed. The problems of film sensitivity, shutter speed, intermittent forward motion of film and of high illumination have all been obstacles. With the perfection of the revolving prism camera by Day, of stroboscopic illumination and synchronized camera by Edgerton, and of the commercial production of supersensitive film, we now have facilities for the magnification of time to effects which are higher than 200 "diameters."

As an example of the application of these new time magnification methods we have been making a study of the behavior responses of adults, infants, children and the higher primates to the sound of a pistol shot. To the naked eye this response is a confused mass of behavior. Using cameras running at a speed of 64 exposures per second it has been possible to demonstrate a clear, unmistakable, immediate, stable, reflex pattern in all the groups we have studied. This primary pattern is very rapid and is usually complete in one-half second or less. The primary response is then followed by a secondary response which is variable, differs among individuals and partakes of the nature of a socialized, conventional, learned response

[1] Th. De Donder and P. Van Rysselberghe, "Thermodynamic Theory of Affinity. A Book of Principles." Stanford University Press, 1936. P. Van Rysselberghe: *Chemical Reviews*, 16: 37, 1935.

[2] H. F. Schott and H. Borsook, SCIENCE, 77: 589, 1933; H. Borsook, *Ergebnisse d. Enzymforschung*, 4: 1, 1935, etc.

[3] P. Van Rysselberghe, Académie royale de Belgique, Bulletins de la Classe des Sciences, December, 1936.

as opposed to the reflex nature of the primary response.

This method has made it possible to sort out the various occurrences in the seemingly very rapid responses following the gunshot. In the infant it is possible to differentiate between the primary startle pattern and the Moro reflex. In the adult we can separate the primary reflex response from the "voluntary jumping," etc. In patients showing Parkinsonian tremor the ultra-rapid photography shows a very brief cessation of the tremor after the gunshot, during which period the elements of the startle pattern appear, followed by resumption of the tremor.

While much can be done, as we have shown, with the relatively small magnification provided by a camera speed of 64 exposures per second, there is much more to be obtained at higher camera speeds. We have now begun to work with cameras capable of running as fast as 3,000 exposures per second. At present, we have results at speeds of 700 and 1,500 exposures per second. We have applied these speeds to the problem of voluntary facilitation of the reflex startle response. With the naked eye, it is impossible to separate the original response from the voluntary facilitation. At both 700 and 1,500 exposures per second, the two can be clearly separated. The primary startle pattern appears first; there is an appreciable interval; and then the "facilitation" appears as a separate response. The uses of this technique in revealing the interrelations of voluntary and involuntary response are evident. A feature of these special cameras is a timing dial included in the photographic field which may be read directly to 0.002 seconds.

The magnification of time in this fashion raises interesting perceptual problems. The dimension of time is an important determinant of the "form quality" or "gestalt" of any experience. The distortion of this one dimension may be sufficient to change the quality of the perceptual pattern. Thus, the facial elements of the startle pattern at normal speed, four times slower than normal, and fifty times slower than normal, are three qualitatively different expressions, their identity evident only if one knows the background of conditions under which the pictures were taken. The first is a "jerk," the second resembles a "hiccup," and the third a stretchy yawn. All three involve the same response with only the speed of presentation changed. Thus, the technique of temporal magnification offers a new approach to the study of time as a factor in perceptual organization.

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CELL INCLUSIONS IN AZOTOBACTER CHROOCOCCUM BEJ.

In a recent issue of this journal[1] I. M. Lewis, discussing the work of Jones, Löhnis and Smith, Mencl, Prazmowski and of Schmidt on the nature of the stainable granules in the cells of *Azotobacter chroococcum*, writes: "There is no indication that any of the other workers performed microchemical or solubility tests to determine whether the stainable bodies are living entities of the cell or lifeless cell inclusions which function as reserve food." He further states that his own investigations showed these to be composed of volutin.

Solely in the interest of truth and as a corroboration of the results reported by Lewis, it may be of interest here to mention a publication of the present author[2] in which, after a long series of microchemical and solubility studies, the writer concludes that "the granulations take the basic dyes and are constituted neither of fats nor glycogen, starch nor chromatine. They seem to be of a metachromatic nature." . . . and that "there is no doubt that metachromatic or, as Meyer terms them, volutine granules were found."

The reserve nature of these bodies was further demonstrated by the preesnt writer[3] by a study of their autophagy.

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SCIENTIFIC BOOKS

STATISTICAL MECHANICS

Statistical Mechanics. By R. H. Fowler. 864 pp. Cambridge: at the University Press. New York: The Macmillan Company. 1937. $14.00.

The first edition of this monumental work, which appeared in 1929 and which we reviewed in this journal,[1] is already a classic in the literature of theoretical physics. So it will suffice to describe the respects in which the second edition differs from the first, both in the presentation of general principles and in the applications to particular problems. The increase in size is immediately apparent. We have always thought the author must have been almost a superman to write a volume as comprehensive as the first edition on such difficult subject-matter. Now, however, the number of pages has grown from 570 to 864, and of numbered equations from 1,607 to 2,344!

[1] J. H. Van Vleck, Science, 70: 41, 1929.

[1] Science, n. s., 85: 16, 1937.
[2] *Jour. Agr. Res.*, 4: 225–239, 1915.
[3] *Jour. Bacter.*, 6: 331–359, 1921.