mass and positive charge will move just like a particle of positive mass and negative charge. However, it will give rise to an electromagnetic field of its own, which is determined entirely by its charge and velocity and is independent of the sign of its mass; hence two such hypothetical particles can be distinguished by the effects they have on other particles, even though they cannot be separated by a mass spectrograph (which determines only the ratio of charge and mass).

Suppose that particles with negative mass should be discovered one day, and suppose that we should succeed in incorporating them into macroscopic matter. Then such matter would not be polarized gravitationally under the influence of an external gravitational field, and therefore it would not exhibit the kind of shielding properties that a dielectric does with respect to electrostatic forces. Only if the negative-mass particles possess an electric charge is it conceivable that such matter would be polarized gravitationally by means of an applied electric field. Even then, if the negative mass of these hypothetical particles should be of the same order of magnitude as the positive mass of particles now known (protons, neutrons, and the like), the shielding effect will be negligibly small.

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Primary Quantum Conversion Process in Photosynthesis: Electron Spin Resonance

Some years ago, on the basis of a study of the kinetics of the Hill reaction in flashing light (*1*), together with a variety of independent observations involving both chemical and kinetic studies of photosynthesis as well as the kinetics of some experiments on luminescence (*2*), a proposal was made concerning the nature of the early processes in the transformation of electromagnetic energy into chemical potential. This proposal involved an ordered array of chlorophyll and collateral molecules, suggested by the structural detail, which has been provided for the photosynthetic organelles of green plants.

The sequence of events was to be an absorption leading to the first excited singlet state of chlorophyll, which then was converted into a triplet excitation, followed by an ionization process that would lead to a trapped electron and a hole, these two entities being the reducing and the oxidizing components which must be simultaneously generated. A part of the process involved the extremely rapid neutralization of the hole by capture of an electron from water, or a product formed from it (*3*). The resultant material would then ultimately appear as molecular oxygen. The electron, on the other hand, would pass through a series of carriers (hydrogen carriers) such as are well known in biochemical processes (thioctic acid, pyridine nucleotide, flavin, and so forth) ultimately leading to the reduction of carbon dioxide.

Although the observation of transient changes in the absorption spectrum of these particles during such a process has been pointed out (*4*), it has been difficult to identify the species responsible from such absorption changes in this complex of pigments. In such a sequence, one might expect another physical property, more characteristic of at least two of these species, to be observable—namely, the magnetism of the triplet state of chlorophyll and the magnetism which would be associated with the trapped, unpaired electrons.

Although the direct observation of the total changes in magnetic susceptibility under illumination would be extremely difficult, it seemed likely to us that the sensitivity of the method of electron-spin resonance might provide the means of making such a direct observation, and work was undertaken toward this end at that time (*5*). Early observations on various kinds of leaves and other plant materials gave indications that such an electron spin signal would appear under illumination, and in the middle of last year a report of the existence of such a light-induced signal in chloroplasts appeared (*6*). From the data presented then, as well as our own at that time, it was not possible to decide on the nature of the material responsible for the signal. This material not only could have been the chlorophyll triplet, as proposed, or the trapped electron, but it may also have been radicals of the semiquinone type among the hydrogen carriers on the path between the trapped electron and carbon dioxide.

One possible way of eliminating secondary chemical reactions as a potential source of the signal is to reduce the temperature at which the illumination is carried out and determine the effect of this on the rate at which the signal appears. A further variable that seemed important to us in the determination of the growth time of the signal was the rate at which quanta of light are actually impinging upon the sample. This we have also varied. And, finally, the nature of the green sample that is being examined may be expected to determine the growth and decay times of all the various magnetic species we have mentioned. The electron-spin resonance spectra of various samples under a variety of conditions were observed at a frequency of 9.3 kMcy/sec (*7*), and the results are given in Table 1.

Table 1. Electron-spin resonance observations on various samples from photosynthetic material. The *g* value of the resonance was 2.00; at room temperature, the width between points of maximum slope was approximately 10 oersteds; at − 140°C, the width between points of maximum slope was approximately 15 oersteds; Light quality: $5800 < \lambda < 8000$ A.

Substance	Light intensity	Temperature (°C)	Signal growth time	Signal decay time
Dried leaves	Low*	25	Minutes	Hours
Dried whole chloroplasts (*8*)	Low*	25	Minutes	Hours
		60	Seconds	Seconds
Wet whole chloroplasts (*9*)	Low*	25	Seconds	Minutes
		− 140	Seconds	Hours
Wet small chloroplast fragments (*9*)	Low*	25	Seconds	Hours
Wet large chloroplast fragments (*9*)	Low*	25	~ 30 sec	~ 30 sec
Wet large chloroplast fragments	High†	25	~ 6 sec	~ 30 sec
Wet large chloroplast fragments	High†	− 140	~ 10 sec	Hours

* Low light intensity: approximately 10^{15} quanta/sec into cavity; the number of free electrons at equilibrium was approximately 10^{16}.

† High light intensity: approximately 10^{16} quanta/sec into cavity; the number of free electrons at equilibrium was approximately 10^{16}.

It is thus clear that the shortest growth times that we have so far observed are definitely limited by the rate at which quanta arrive at the sample. Second, it is clear that cooling to − 140°C— at this temperature we may expect that none of the ordinary enzymatic reactions will proceed at measurable rates—does not significantly lengthen the time required for the full signal to appear, while it does very materially lengthen the time required for the signal to disappear after the light is turned off. These facts are consistent with the idea that the signal is produced by the product of a physical process only, as distinct from an enzymatic or chemical one, as we normally conceive of it. The observation of a thermal luminescence and semiconductivity for dried chloroplasts has recently been reported and interpreted as consistent with the idea that the chloroplasts have some of the properties of semiconductors (*8*).

The asymmetry of the signal itself (*7*), together with the fact that the decay and probably the growth is not a simple, single logarithmic one even at -140°C, seems to indicate that more than one species is responsible for the over-all signal which we see. Among these species may be the chlorophyll triplet (as mentioned earlier), the trapped electron, and, finally, some species of free radical resulting from the direct dissociation of a chemical bond in the absorption act. While it is possible to suppose that the cooling would enhance the lifetime of the chlorophyll triplet to the extent of hours, it does not seem likely. We are thus left with the trapped electron and the possibilities of a dissociated bond.

It is perhaps worth noting that, whatever the nature of the unpaired electron producing this signal, its coupling with the lattice around it must be rather poor in order that it can produce a signal as narrow as the one we see. This suggests that it is located in a rather delocalized pi-type of orbital. It is to be expected that improvements in technique will lead to a more precise identification of the variety of unpaired electrons which almost certainly result from the illumination of the photochemical apparatus in plants.

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Effect of Psychiatric Disorder on Visual Thresholds

Following a wartime observation that neurotic patients tended to obtain lower scores than normal subjects on tests of "night vision," several experiments (*1*) have been undertaken in which the night vision of normal, neurotic, and psychotic groups has been compared. A fairly consistent finding of this research is that, on the average, psychiatric patients have raised intensity thresholds during the course of dark adaptation (*2*).

The most general effect of psychiatric disorder is, apparently, to elevate the dark-adaptation curve along the log-luminance axis without changing its shape (see Fig. 1). The extent of the displacement varies somewhat from one investigation to another between about 0.1 and 0.5 $\log_{10}$ unit. The effect of psychiatric disorder seems to be equivalent to that of placing a neutral density filter in front of the subject's eyes, thus necessitating a greater amount of light to produce a threshold response.

In this respect, the effect of psychiatric disorder may be compared with that of anoxia, which also tends to shift the dark-adaptation curve along the intensity axis without affecting its shape, by amounts varying between 0.1 and 0.4 $\log_{10}$ unit, depending on the degree of anoxia (*3*). A similar effect has been produced by insulin hypoglycemia (*4*) and by alcohol (*5*). In all three cases, the most plausible explanation of the effect seems to be that these conditions lead to a depression of central nervous activity, either in the retina or at higher levels of the visual system.

It seems possible that some of the effects of psychiatric disorder on visual thresholds may also reflect changes in the nervous system of a similar type. Oxygen deficiency has from time to time been reported to occur in psychotics and to a lesser extent in neurotics (*6*), while Gellhorn *et al.* (*7*) have reported more insulin in psychotic patients than in normal subjects, under stress conditions. More recently Shagass and Naiman (*8*) have provided evidence of a reduced central excitability in hysterics, as determined by their "sedation thresholds" for sodium amytal. Although the evidence on the physiological side is far from satisfactory, it would seem that a hypothesis of lowered central excitability in the visual system merits at least as much consideration as possible alternative explanations of a more psychological nature phrased in perceptual terms (for discussion, see *2*).

The implications of the experimental results and the suggested hypothesis may be considered from several points of view. As far as visual research on dark adaptation is concerned, it should be noted that psychiatric disorder does not in general alter either the *shape* of the dark-adaptation curve or the total *range* of adaptation; hence, it seems unlikely that the actual mechanism of adaptation is affected. The shift of the curve along the intensity axis can be accounted for in terms of a depression of activity in the visual pathways, completely unrelated to the dark-adaptation process itself. The results do not, therefore, conflict with the photochemical theories of dark adaptation proposed by Hecht and others, nor do they provide any evidence for neural mechanisms in dark adaptation. They may, however, like the studies of anoxia, suggest the need for a broader basis for visual theories by forcing photochemical theorists to make explicit and develop factors that are implicit in their equations and regarded as secondary or constant (for example, the efficiency with which the conducting system deals with the products of photochemical reactions).

From the broader viewpoint of psychiatry, abnormal psychology, and neurophysiology, the results are perhaps of greater interest, for they may provide further evidence of the value of visual thresholds as indicators of changes of excitability of the central nervous system. As McFarland (*9*) has pointed out, visual thresholds appear to have certain advantages over other psychophysiological functions as quantitative indices of "physiological imbalance" with regard to sensitivity, to the precision with which the physical measurements involved can be made, and to the fact that the subject is not aware of the changes in the physical intensity of the stimulus that are necessary for him to see it, since at threshold the stimulus always has the same appearance. However, like critical flicker frequency (CFF), now being widely used for this purpose, absolute thresholds taken during dark adaptation are not specifically related to any particular physiological stress or abnormal condition. This would seem to reduce their practical value in psychiatric diagnosis.

From the results so far obtained, there seems no immediate likelihood of distinguishing, on the basis of threshold measurements alone, psychotics from neurotics, hysterics from depressives and psychopaths, or, for that matter, psychiatric patients suffering from functional disorders from patients having various organic diseases. In consequence, considerable caution is necessary when results are interpreted from the psychiatric viewpoint and, as Simonson and Brozek (*10*) point out elsewhere in their review of studies of critical flicker frequency, "As a rule, additional information obtained by independent methods is desirable for more specific correlations."

In spite of this, the possibility should not be overlooked that more detailed ex-