traversed by the deuterons exhibits the change in color, while in others a transition occurs throughout the whole crystal, due to the strong gamma-radiation accompanying the bombardment. Often the effect exhibits a reversal; that is, if the intensity of the bombarding beam is too great, the change of color appears at the edges but not at the center of the bombarded area. The color changes produced by deuteron bombardment unlike those due to x-rays show little inclination to fade out, but disappear abruptly if heated through a certain critical temperature.

The following are representative of the induced colors observed for specific crystals:

Alkali halides, NaF—light red; NaCl—amber to black depending on the exposure; NaI—yellow to green; KCl—purple; KBr—deep blue; KI—green. Colors in most cases disappear on heating to about 220°C; glass, a dark amber color, clears on heating to about 300°C.

Fluorite—induced color is a body effect and depends on the original tint varying from green to amethyst.

Quartz—clear crystals show only surface darkening but if originally tinted, as rose quartz, turns to purplish brown throughout.

Beryl—aquamarine and emerald differ only in color, green color not induced in aquamarine by bombardment.

Diamond—inferior amber colored stones assume a green body coloring equivalent to that of the rare natural gems. The change is permanent for ordinary temperatures. On heating to about 900°C the original color returns. The color produced depends somewhat upon the original tint, clear stones showing less change than those with original color. In one case a bluish color was produced.

It is of considerable interest that the metastable states produced by the ejection of electrons by the ionizing radiations can exist at ordinary temperatures indefinitely.

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[1] See, for example, Doelter, *Das Radium und die Farben* (1910); P. S. Bayley, Phys. Rev. **24**, 495 (1924); P. G. N. Nayar, Proc. Ind. Acad. Sci. **14**, 1 (1941).

Anomalous Scattering of Mesons

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In two recent papers in this journal Code and Shutt[1] have described measurements of the anomalous scattering of mesons due to their interaction with nuclear particles. The cross section obtained was of the order of magnitude of 0.6×10^{-27} cm^2 per nuclear particle, for a selected sample of mesons having an average energy of 0.8×10^9 ev in Code's measurements. The energy was not measured in Shutt's experiment. We wish to point out that these results like previous measurements by Wilson[2] are in reasonable agreement with the meson theory of nuclear forces if we assume a spin 1 or 0 (pseudoscalar mesons) for the meson. We need not make any further *ad hoc* assumptions. The apparent discrepancy of earlier calculations[3] with the experiments is due to the fact that the usual expansion method, under the assumption that the meson-nucleus interaction is small, breaks down at high energies. The reason is that the coupling of the meson with the charge and spin degrees of freedom of the nuclear particles becomes increasingly strong at high energies.[4] It has now been shown by Wilson and by one of us[5] that a more exact quantum mechanical treatment of the scattering problem is possible which differs from the usual expansion method essentially by the inclusion of *damping*. The cross section thus obtained is in units of

$$(\hbar/\mu c)^2 = 5\times 10^{-26}\ \text{cm}^2 \quad (\mu = \text{meson mass})$$

$$\sigma = 4\pi f'^2 \frac{G^2 p^4}{\epsilon^2(1+\kappa^2)}, \quad \kappa = G^2 p^3/\epsilon, \quad G^2 = g^2 + 2f^2 + f'^2, \quad (1)$$

where p, ϵ are the momentum and energy of the meson in units of the rest energy μc^2, and g, f, f' are the ordinary coupling constants for longitudinal, transverse, and pseudoscalar mesons, divided by $(\hbar c)^{\frac{1}{2}}$. (The primary meson is assumed to be pseudoscalar.) Some of these constants may be zero, but we believe that the best account of all experimental facts is obtained if they are all different from zero. All three are then of the order of magnitude $g^2 \sim f^2 \sim f'^2 \sim 1/10$. For energies of 0.8×10^9 ev σ becomes of the order of magnitude of 1.8×10^{-27} cm^2 which—in view of the scanty experimental material and our insufficient knowledge of the constants g, f, f'—may be considered as in reasonable agreement with the measurements quoted above. It must also be remembered that (1) is derived for an infinitely heavy nuclear particle and that the motion of the heavy particle will probably diminish the cross section by a factor 2 or so as ϵ approaches the value Mc^2.

Formula (1) has also been derived recently by Fierz[6] by a semiclassical treatment of the charge degree of freedom. It is also very similar to the cross section for a particle scattered by a classical magnetic dipole field.[7] This is not very surprising in view of the great similarity between the formalisms describing the spin and the charge.

Attempts have previously been made to explain the small experimental value of the anomalous scattering by introducing the hypothesis that the proton-neutron can exist in excited charge and spin states by which the inertia of the charge and spin degrees of freedom would be increased.[8] While this possibility has to be kept in mind we believe now that so far no sufficient foundation for such an hypothesis exists.

The quantum theory of damping can be developed in quite a general way. After the diverging self energies and other similar diverging integrals have purposely and systematically been omitted, a new set of equations can be obtained which is free from any singularities and differs from what is obtained by the usual expansion method by the inclusion of damping. The theory makes no assumption about the strength of the coupling. For a number of examples [compare, for instance, (5)] it can be seen that this damping corresponds to that part of the classical damping which is independent of the size and structure of the particle, but, of course, there is not always a classical analogy. The theory can, without difficulty, also be applied to the multiple processes ("explosions") occurring as a consequence of the meson theory and the results turn out reasonably in every respect. These questions are dealt with in a paper to appear shortly in the *Proceedings of the Cambridge Philosophical Society*.

[1] F. L. Code, Phys. Rev. **59**, 229 (1941); R. P. Shutt, Phys. Rev. **61**, 6 (1942).
[2] Wilson, Proc. Roy. Soc. **174**, 73 (1940).
[3] Heitler, Proc. Roy. Soc. **166**, 529 (1938).
[4] The case of "strong coupling" has recently been studied by Wentzel [Helv. Phys. Acta. **13**, 269 (1940)] and by J. R. Oppenheimer and J. Schwinger, Phys. Rev. **60**, 150 (1941).
[5] Heitler, Proc. Camb. Phil. Soc. **37**, 291 (1941); Wilson, Proc. Camb. Phil. Soc. **37**, 301 (1941).
[6] Fierz, Helv. Phys. Acta. **14**, 257 (1941).
[7] Bhabha, Nature **145**, 819 (1940); Proc. Ind. Acad. Sci. **11**, 247 (1940); Proc. Roy. Soc. **178**, 314 (1941); Bhabha and Corben, Proc. Roy. Soc. **178**, 273 (1941).
[8] Heitler, Nature **145**, 29 (1940); Bhabha, Proc. Ind. Acad. Sci. **11**, 347 (1940); **13**, 9 (1941); Heitler and Ma, Proc. Roy. Soc. **176**, 368 (1940).

The Effect of Polarized Light on the Absorption Spectrum of the Neodymium Ion in Crystals

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It has been found that the visible absorption spectrum of certain crystals containing neodymium is dependent in a striking manner upon the polarization of the light passing through the crystal. During the last year and a half after we discovered the effect in crystals of neodymium chloride we have examined the absorption spectra, using polarized light, of neodymium nitrate, sulphate, and bromate, and have obtained a quantum mechanical explanation of the effect.

The bromate spectrum has been so fruitful in giving a clue to the nature of the effect that we present in this preliminary note a photograph (Fig. 1) of a small section of it

Fig. 1. Absorption of $Nd(BrO_3)_3 \cdot 9H_2O$ near 5750A when polarized light is sent through the crystal perpendicular to optic axis.

taken with the Hilger E1 spectrograph. Fortunately the crystal is uniaxial and has a known structure.[1] The salient feature is the group of five electronic lines spread over a region of 70A near 5750A which is produced by light passing through a crystal plate 0.5 mm thick, cut with the optic axis lying in the surface of the plate. The spectrum marked π is produced by light polarized with the electric vector parallel to the optic axis, and the other marked σ occurs when the electric vector is perpendicular to the axis. When light is sent along the optic axis, only the σ spectrum is observed. The five lines are assumed to correspond to transitions from the lowest component of the ground level $^4I_{9/2}$ of the neodymium ion, which is split by the crystal field, to components of an electrically split upper level.

The levels of the free ion are characterized by values of L and J, the total orbital angular momentum, and total angular momentum quantum numbers, respectively. In a weak crystal field the degeneracy for the free ion caused by the fact that states of different M values (projection of J on the singular axis of the crystal) have the same energy, is partially removed. This effect causes the eigenfunctions of the perturbed levels to be linear combinations of the unperturbed eigenfunctions of the free ion. We have calculated in zero-order approximation, using perturbation and group theory methods, how the unperturbed functions mix to produce the perturbed ones, and have explained the observed polarizations as arising from the particular way in which this mixing occurs. It is found, for example, that the unperturbed functions characterized by the values $\pm\frac{1}{2}$, $\pm 5/2$, $\pm 7/2$ for M enter several perturbed states for $J=9/2$; in fact these values describe the ground state. Those characterized by $M=\pm\frac{3}{2}$ enter others. Transitions from a level of the first type to one of the second involve changes in M of $\Delta M=\pm 1$. Transitions involving $\Delta M=0$ are not present. According to electric dipole selection rules (which we can show operate here) lines corresponding to these transitions are polarized with the electric vector perpendicular to the singular direction of the crystal. On the other hand, transitions between levels of the first type involve changes corresponding to $\Delta M=0$ as well as changes corresponding to $\Delta M=\pm 1$. Lines of this type may be predominantly π lines, or they may be unpolarized. If each one of the six unperturbed eigenfunctions enters the level $M(\pm\frac{1}{2}, \pm\frac{5}{2}, \pm 7/2)$ with equal coefficients, it turns out that the transition produces a predominantly π line. We have accounted in this way for the polarization of most of the lines in four groups throughout the visible region in the bromate spectrum.

The complete work is described in a doctorate thesis written by one of us (R. W. K.) and is being prepared for journal publication.

[1] L. Helmholz, J. Am. Chem. Soc. **61**, 1544 (1939).

On Perturbations Causing Apparent Convergence in the C_2 Spectrum

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On the basis of the rotational analysis of some $^1\Pi-{}^1\Pi$ Deslandres-d'Azambuja and tail bands of the C_2 molecule, carried to moderate rotational quantum numbers only, by Herzberg and Sutton[1] these authors assume a convergence limit about 35,900 cm^{-1} above the lower $^1\Pi$ state of C_2.

In this laboratory an extensive search has been started concerning perturbations in the C_2 spectrum and well-exposed plates of the $^1\Pi-{}^1\Pi$ system disclose that (1) the bands could be followed up to rather high rotational quantum numbers, the involved upper $^1\Pi$ states being several thousand cm^{-1} units higher in energy than 35,900 cm^{-1} above the lower $^1\Pi$ state; and (2) while upper and lower $^1\Pi$ states show numerous local perturbations, which bring in either both or sometimes only the one Λ-type doubling components (Herzberg and Sutton's analysis ends at such