gen, da der Carbazol-Chromophor stärker absorbiert als der Naphthalin-Chromophor[3]. Bei keiner Anregungswellenlänge (und bei Messung mit sehr hoher Geräteempfindlichkeit) wurde das Auftreten einer Carbazol-ähnlichen Phosphoreszenz beobachtet. Das Phosphoreszenzspektrum des N-Naphthyl-carbazols ist von der Anregungswellenlänge vollkommen unabhängig.

Der *intramolekulare* Fall von Triplett-Energieübertragung und sensibilisierter Phosphoreszenz ist bisher nur an Systemen bekannt geworden, bei denen die Donator-Komponente (z. B. Benzophenon-Rest) und die Acceptor-Komponente (z. B. Naphthalin-Rest) durch CH_2-Gruppen isoliert sind[4]. Bei dem hier untersuchten N-(α-Naphthyl)-carbazol scheint nun erstmalig der Fall einer intramolekularen Triplett-Energieübertragung und sensibilisierten Phosphoreszenz vorzuliegen, bei dem die Donator- und die Acceptor-Komponente auf Grund *sterischer* Faktoren voneinander isoliert sind. — Über den Mechanismus der Energieleitung können noch keine Aussagen gemacht werden.

Die Untersuchungen sollen an anderen N-Aryl-carbazolen fortgeführt werden.

Experimentelles: N-(α-Naphthyl)-carbazol): Aus Carbazol-Natrium (aus Carbazol und Natriumamid) durch Umsetzung mit 1-Bromnaphthalin bei 180°. Reinigung durch Chromatographie an Al_2O_3/Benzin, Reinheitsprüfung spektroskopisch und durch Papierchromatographie. N-(α-Naphthyl)-carbazol bildet (aus Benzin) farblose Nadeln vom Schmp. 127–128°. Charakteristische IR-Banden (KBr): 801, 775, 763, 725/cm (γ-CH).

$C_{22}H_{15}N$ (293,1)	Ber.	C 90,07	H 5,15	N 4,78,
	Gef.	C 89,72	H 5,27	N 5,01.

Durchführung der Messungen: Für die Messungen verwendete man ein Aminco-Keirs-Spektrophosphorimeter (Empfänger: Multiplier RCA 1P28). Das Lösungsmittel war in allen Fällen eine Mischung von Alkohol-Isopentan-Äther 2 : 5 : 5 (EPA). Meßtemperatur: 77 °K.

Für experimentelle Hilfe danke ich den Herren K. Bullik und D. Kampf.

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[3] Das gilt für Wellenlängen > 230 mμ. Mit kürzeren Wellenlängen wurde nicht angeregt.

[4] A. A. Lamola, P. A. Leermakers, G. W. Byers u. G. S. Hammond, J. Amer. Chem. Soc. **87**, 2322 [1965].

Scattering Cross Section of a Particle Beam

Michal Lenc

Institute of Instrument Technology,
Laboratory of Electron Optics,
Czechoslovak Academy of Sciences, Brno

(Z. Naturforsch. **23 a**, 952—953 [1968]; received 1 March 1968)

Using usual methods the scattering cross section of a beam of wave packets is derived.

The scattering cross section for a beam of wave packets was shown to be the superposition of cross sections of plane wave components of the wave packet[1]. We derive this interesting result in a more usual way. The transition probability per unit time into the state defined by quantum numbers (a, E_a) is (see e. g. Newton[2])

$$w_a(t) = -i \int \mathrm{d}b \int \mathrm{d}c \int \mathrm{d}E_b \int \mathrm{d}E_c\, f(E_b, b)\, f^*(E_c, c)\, \tau_{ab}^{(+)} \tau_{ac}^{(+)} \cdot \exp(i(E_c - E_b)\, t) \, [(E_c - E_a - i\,\varepsilon)^{-1} - (E_b - E_a + i\,\varepsilon)^{-1}] . \tag{1}$$

Here $\tau_{ab}^{(+)}$ is the off-the energy shell extension of the transition matrix,

$$\psi_0(t) = \int \mathrm{d}b \int \mathrm{d}E_b \exp(-i\, E_b\, t)\, \psi_0(E_b, b)$$

is the incoming wave packet.

The total transition probability is $W_a'' = \int \mathrm{d}t\, w_a(t)$,

$$W_a'' = (2\,\pi)^2 \int \mathrm{d}b \int \mathrm{d}c\, f(E_a, b)\, f^*(E_a, c) \tau_{ab}(E_a)\, \tau_{ac}(E_a) . \tag{2}$$

An "usual" packet is described by

$$f(E_b, b) = m\, k_b\, f(\boldsymbol{k}_b) .$$

The transition probability into the state with the momentum in an element of solid angle $\mathrm{d}\Omega$ is

$$W_a' = \int \mathrm{d}E_a\, \varrho(k_a)\, W_a'' ,$$

where with the wave function

$$\psi_0(\boldsymbol{x} \mid E_a, a) = \exp(i\, \boldsymbol{k}_a \boldsymbol{x})$$

the density of states is

$$\varrho(k_a)\ \mathrm{d}E_a = (2\,\pi)^{-3}\, k_a^2\, \mathrm{d}k_a\, \mathrm{d}\Omega_a .$$

The z-axis is chosen along some median flux direction. The beam is considered to be composed of packets displaced relative to each other in the xy-plane. Denoting the displacement by $\boldsymbol{h}$, we obtain

$$\tau_{\boldsymbol{k}_a \boldsymbol{k}_b}^{(+)}(\boldsymbol{h}) = \tau_{\boldsymbol{k}_a \boldsymbol{k}_b}^{(+)} \exp(i\, \boldsymbol{k}_b \boldsymbol{h}) .$$

Then the distribution of the total flux in the z-axis direction is homogeneous

$$j_z = \int \mathrm{d}h_x \int \mathrm{d}h_y \int \mathrm{d}t\, j_z(\boldsymbol{h}) = (2\,\pi)^3 \quad \mathrm{d}\boldsymbol{k}\, |f(\boldsymbol{k})|^2 . \tag{3}$$

Similar calculations lead to the expression for the transition probability

$$W_a = \int \mathrm{d}h_x \int \mathrm{d}h_y\, W_a'(\boldsymbol{k}) = 2\,\pi\, m^2\, \mathrm{d}\Omega_a \int \mathrm{d}\boldsymbol{k} \frac{k}{k_z}\, |f(\boldsymbol{k})|^2\, |\tau_{\boldsymbol{k}_a \boldsymbol{k}}(k)|^2 . \tag{4}$$

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[1] A. Katz, J. Math. Phys. **7**, 1802 [1966].

[2] R. G. Newton, Scattering Theory of Waves and Particles, McGraw-Hill, New York 1966, p. 215.

In both (3) and (4) eqs. the back scattered wave was neglected.

The cross section is defined as

$$d\sigma_a = W_a \, j_z^{-1}. \tag{5}$$

The cross section of the $\boldsymbol{k}$-component of the wave packet is

$$d\sigma_a(\boldsymbol{k}) = (m/2\,\pi)^2 \, | \, \tau_{\boldsymbol{k}_a \boldsymbol{k}} \, (k) \, |^2 \, d\Omega_a \, . \tag{6}$$

Substituting (3), (4) and (6) into (5) and supposing $\int d\boldsymbol{k} \, | \, f(\boldsymbol{k}) \, |^2 = 1$, we obtain

$$d\sigma_a = \int d\boldsymbol{k} \frac{k}{k_z} \, | \, f(\boldsymbol{k}) \, |^2 \, d\sigma_a(\boldsymbol{k}) \, . \tag{7}$$

Our expression is identical with Katz's (3.7) [1]: the scattering cross section of a beam of wave packets produced by an incoherent extended source is given by the superposition of the cross sections of $\boldsymbol{k}$-components of the wave packet.

Chemical Reactions Resulting from Heavy Particle Bombardment of Diamond

Edward J. Zeller and Gisela Dreschhoff

Department of Geology, University of Kansas
Lawrence, Kansas, USA

(Z. Naturforsch. **23 a**, 953—954 [1968]; received 21 December 1967)

Irradiation of natural diamond crystals with protons and deuterons ranging in energy from 0.7 to 1.5 MeV has been found to produce infrared absorption bands which are apparently related to the formation of hydrocarbons. The process is essentially analogous to the formation of hydroxyl ions by proton irradiation of silicates [1].

In the experiments reported here, the particle beam was supplied by a model Km, 3 MeV Van de Graaff accelerator manufactured by High-Voltage Engineering Inc. The irradiations varied in duration from two to twenty-seven hours with an average current of 1.5 μA on the target holder. Approximately 5×10^{15} particles per hour were incident upon the crystal. In all cases the crystal was smaller than the beam diameter, and all irradiations were made with a de-focused beam so that the proton intensity distribution across the beam was as uniform as possible. The proton energy range between 0.7 and 1.5 MeV was selected in order to reduce nuclear reactions and to insure a depth of penetration which would permit retention of the reaction products.

Natural diamonds were found to be the most satisfactory target material because they are transparent to infrared radiation throughout most of the spectrum where hydrocarbon absorption bands would be expected. The diamonds used for the study were flat cleavage plates of approximately 1 mm thickness, having surface areas of 10 to 15 mm^2. They were mounted in lead plates or imbedded in Wood's metal in copper holders and were in thermal contact with a dewar containing liquid nitrogen. The targets were cooled in order to retard escape of any of the volatile hydrocarbons which might be produced.

Very strong blue luminescence was noted at the beginning of each of the initial irradiations. This luminescence decreased rapidly in intensity but did not disappear entirely for approximately an hour. In several instances the diamonds were found to be in poor thermal contact with the liquid nitrogen dewar. In these cases, the luminescence changed very rapidly from a strong blue to a dark green. The diamonds were colored black in visible light in all cases, irrespective of the nature of the bombarding particles.

The infrared absorption measurements were made using a Perkin-Elmer model 421 infrared spectrophotometer. Absorption curves of the diamond crystals were measured before irradiation and after each subsequent particle dose. After each irradiation and before measurement of the infrared absorption curve. the surfaces of the diamonds were cleaned with steel and glass wool. Crystals were then examined under a microscope to make sure that any external deposits which had been transported to the target by the ion beam had beem removed. Differential curves were obtained by subtracting the normalized infrared absorption curve of the irradiated crystal from the normalized absorption curve of the same crystal before irradiation.

An initial irradiation resulted in the development of a series of absorption lines which increased in intensity and definition when the total proton dose was increased by successive irradiations. Differential absorption spectra of proton and deuteron irradiated diamonds are shown in Fig. 1. The absorption peaks which are shown in the proton and deuteron differential curves include fundamental absorption frequencies and their overtones and combinations which are characteristic of CH and CD bonds [2]. The deuteron irradiations were made in order to test the hypothesis that the infrared absorption lines which appeared after proton irradiations resulted from hydrocarbons formed in the crystal. Owing to the greater mass of the deuterium nucleus, the absorptions which result from deuterated hydrocarbons are shifted in wavelength.

A further test using ^{3}He nuclei was conducted to eliminate the possibility that the absorption peaks resulted from radiation induced defects and not from hydrocarbons. If radiation induced defects caused the absorptions, similar peaks should be developed irrespective of the nature of the bombarding particles. The ^{3}He nuclei blackened the crystals, as in the case of the other radiations; but absorption bands were not developed at wavelengths of the principal CH or CD absorptions.

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[1] E. J. Zeller, L. B. Ronca, and P. W. Levy, J. Geophys. Res. **71** (20), 4855 [1966].

[2] R. T. Conley, Infrared Spectroscopy, Allyn and Bacon, Boston 1966.