assumed that the ζ^0-meson is emitted at this angle θ with an energy γ_0 given by[4]

$$\gamma_0(\theta)=\frac{\bar{\gamma}_0\bar{\gamma}(1+\tan^2\theta)\pm(\bar{\gamma}_0-1)^{\frac{1}{2}}(\bar{\gamma}-1)^{\frac{1}{2}}[1-(\bar{\beta}^2/\bar{\beta}_0^2-1)\bar{\gamma}^2\tan^2\theta]^{\frac{1}{2}}}{1+\bar{\gamma}^2\tan^2\theta}.$$

A monoenergetic spectrum for $\bar{\gamma}_0$ in the center-of-mass system was assumed and the variation of γ_0 with θ was calculated for $20\leqslant\bar{\gamma}\leqslant 50$ with $\bar{\gamma}\geqslant 5$. In this way it was possible with a given θ_s and θ to determined $\gamma_0(\theta)$ and therefore θ_M; Q was taken as 6 Mev. Thus if $\theta_s\leqslant\theta_M$ this pair of mesons could presumably have arisen from the proposed ζ^0 decay scheme.

A total of 21 showers were examined encompassing 278 diffuse shower particles. It was found that the angular separation θ_s for 31 pairs of these particles was such that they could have arisen from ζ^0-meson decay; the criterion $\theta_s\leqslant\theta_M$ was insensitive to the particular choice of parameters given above. On the other hand we expected a certain number of electron-positron pairs arising from the conversion of γ-rays resulting from the two photon decay of the neutral meson. Using the value[3] of 0.41 for the ratio of neutral mesons to charged particles and taking into account a finite lifetime for the π^0-meson,[5] we find that at least 26 electron-positron pairs are expected to appear in the observation area: we find then on the assumption that all the charged shower particles observed are π-mesons that 4 ± 4 percent[6] of these mesons can arise via the scheme $\zeta^0\rightarrow\pi^++\pi^-+Q(<6$ Mev). We believe, however, that our data do not require the introduction of this new particle to explain the observed angular correlations.

A possible explanation of the observations of Danysz, Locke, and Yekutieli has been suggested by Brueckner and Watson.[7] They suggested that the observed angular correlations of Danysz *et al.* are due to distortions introduced in the outgoing meson wave function by an attractive meson-meson potential: this might be expected to have a relatively strong influence for the relatively low energy mesons observed in low multiplicity showers, whereas it would be expected to be a very small effect in the very high energy showers reported on in this note.

[1] Danysz, Lock, and Yekutieli, Nature **169**, 364 (1952).
[2] M. F. Kaplon and D. M. Ritson, Phys. Rev. **85**, 932 (1952).
[3] M. F. Kaplon and D. M. Ritson, Phys. Rev. to be published.
[4] Bradt, Kaplon, and Peters, Helv. Phys. Acta **23**, 24 (1950).
[5] Kaplon, Peters, and Ritson, Phys. Rev. **85**, 900 (1952).
[6] B. Peters (private communication) has made an analysis similar to ours in the diffuse cone of energetic showers and finds no evidence for the existence of the ζ^0-meson. Danysz and co-workers find on the assumption of the existence of the ζ^0-meson that 10 percent of the charged π-mesons arise from its decay; J. Y. Mei and E. Pickup, Phys. Rev. **86**, 796 (1952) report a similar figure if the ζ^0 is assumed to exist.
[7] K. A. Brueckner and K. M. Watson, Phys. Rev. **87**, 621 (1952).

Some Effects of Ionizing Radiation on the Formation of Bubbles in Liquids*

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(Received June 12, 1952)

FOR many problems connected with the study of high energy nuclear events and their products in cosmic-ray interactions, it would be very desirable to have available a cloud-chamber-like detector whose sensitive volume is filled with a hydrogen-rich medium whose density is of the order of 1 g/cc. In investigating possible ways of making such an instrument, it seemed promising to try to make a device which takes advantage of the instability of superheated liquids against bubble formation in the same way that a Wilson cloud chamber utilizes the instability of supercooled vapors against droplet formation.

A macroscopic continuum theory of the stability of small bubbles in a superheated liquid has been developed which predicts that bubbles carrying a single electronic charge will tend to collapse more readily than uncharged bubbles, while bubbles carrying two or more charges will be unstable against rapid growth under some circumstances. On the basis of this picture one can estimate the conditions of temperature and pressure under which a pure liquid in a clean vessel becomes unstable against boiling due to the presence of ions.

An experimental test of the theory for radiation-induced ionization was made by maintaining diethyl ether in a thick-walled glass tube at a temperature near 130°C and under a pressure of about 20 atmospheres. In the presence of a 12.6-Mc Co^{60} source, the liquid in the tube always erupted as soon as the pressure was released, while when the source was removed, time delays between the time of pressure release and eruptive boiling ranged from 0 to 400 seconds with an average time of about 68 seconds. The average time between successive traversals of the tube by a hard cosmic-ray particle is estimated to be 34 seconds.

A second test was made by removing the Co^{60} source from its lead shield at a distance of 30 feet from the ether tube while the latter was sensitive and waiting for a cosmic-ray or local ionizing event. In every case the tube erupted in less than a second after exposure to the source.

A "coincidence telescope" consisting of two parallel tubes was constructed and coincidences apparently resulting from vertical cosmic rays were observed with roughly the expected ratio of single to coincident eruptions. The coincident bubbles occurred near each other in the two neighboring tubes, but other single events occurred at random at different places in the tubes.

According to the proposed explanation of the radiation sensitivity of bubble formation, one expects the threshold conditions of temperature and pressure of the system to be different for the formation of bubbles carrying 2, 3, 4, or more elementary charges. The shapes of the observed delay time curves for different pressures and temperatures are consistent with this expectation.

On the basis of the suggested model for the observed phenomena, it is possible to estimate with the aid of a statistical hole theory of liquids the influence of ionizing radiation and ionic impurities on phenomena such as turbulent and supersonic cavitation, tensile strength and compressibility of liquids, scattering of supersonics in liquids near their boiling points, "bumping" of boiling liquids, maximum attainable superheats in liquids, etc. Further details concerning the experimental and theoretical aspects of the problem will be published elsewhere.

The author wishes to thank Messrs. G. Kessler and A. G. Dockrill for their expert work in constructing the glass parts of the apparatus.

* This work was supported by the Michigan Memorial-Phoenix Project and a grant from the Horace H. Rackham School of Graduate Studies.

Effect of Radiation on Elastic Constants

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(Received June 12, 1952)

DIENES[1] has recently published a calculation of the effect of interstitial ions and vacant lattice sites on the elastic constants of copper and sodium. He finds that 1 percent of vacant lattice sites decreases all the elastic constants by about 1 percent, while 1 percent of interstitial ions increases some of the lattice constants of copper by 10 percent. He uses an approximation in which the distorted lattice deforms homogeneously under a homogeneous applied stress; the large increase of energy around interstitial ions which are already abnormally close to their neighbors gives rise to large increases in the elastic constants. The purpose of the present note is to show that this approximation overestimates the difference between the effects of interstitial ions and of vacant lattice sites, because a homogeneous applied stress will produce less distortion near an interstitial ion than it does in the matrix, and, similarly, more distortion near a vacant site. This may most readily be seen by considering the limiting case in which the interstitial ion is rigidly wedged between its neighbors. On Dienes's approximation this rigid wedging would make an infinite contribution to the elastic constants. One can in fact make an approximate estimate for this case by regarding the interstitial ion as a rigid and incompressible sphere of radius $\delta/2$ and volume $2\pi/3$ of the atomic volume. If 1 percent of interstitial ions is represented by $2\pi/3$ percent by volume of incompressible spheres inserted in an isotropic elastic continuum, a calculation by Bruggeman[2] shows that the bulk modulus is increased by $2\pi(3K+4G)/9K \simeq 3.8$ percent. On a similar approximation, 1 percent of vacant lattice sites, representing 1 percent by volume of spherical holes, reduces the bulk modulus by $(3K+4G)/4G \simeq 2.3$ percent. Here K is the bulk modulus and G the rigidity of the matrix, and the numerical values are taken for Poisson's ratio 1/3, $K=5G/3$.

[1] G. J. Dienes, Phys. Rev. **86**, 228 (1952).
[2] D. A. G. Bruggeman, Ann. Physik **29**, 160 (1937).

Effect of Radiation on Elastic Constants*

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(Received July 2, 1952)

THE writer pointed out in his original paper[1] that the major approximation of the theory comes from replacing the distorted lattice, which is locally inhomogeneous, by an approximately equivalent homogeneous material. No attempt was made to evaluate the influence of this inhomogeneity except in so far as an average was taken whereby the interactions ascribable to the vacancies and interstitials were smeared over the whole crystal. Nabarro[2] points out some of the weaknesses of this approximation and proposes an estimate based on an average derived from the theory of elasticity of an isotropic continuum. The physical argument given by Nabarro is certainly correct, and the question of the validity of the various approximations centers around the problem of properly averaging the elastic constants in an inhomogeneous medium. This problem in elasticity theory does not appear to be completely solved. For example, Bruggeman[3] and Mackenzie[4] are not in good quantitative agreement concerning the shear moduli of an isotropic material containing holes.

Within the framework of Bruggeman's theory the writer would like to make the following comments concerning Nabarro's calculations:

(1) The writer has underestimated in the original paper the decrease in elastic moduli caused by vacant lattice sites, i.e., the moduli are decreased by more than a bulk effect, as pointed out by Nabarro (2.3 percent *vs* 1 percent).

(2) The writer believes that Nabarro underestimates the influence of the interstitials by underestimating the effective volume over which the elastic moduli are greatly increased. Next nearest neighbors of an interstitial are strongly influenced by the presence of the interstitial particularly after relaxation has occurred, and it seems reasonable to consider the effective volume to have a radius of $\sqrt{3}\delta/2$. The corresponding volume percent is $2\sqrt{3}\pi$ of the atomic volume, and the increase in bulk modulus is 19.6 percent for one percent interstitials. As a more conservative estimate it may be assumed that the effective volume is half-way between this and Nabarro's estimate. The corresponding increase in the bulk modulus is 11.1 percent. Thus, the writer's original averaging process, which gave about 9 percent, seems very reasonable. The somewhat higher contribution of the vacancies should be subtracted out, of course, but the main conclusions of the original paper are not changed.

(3) It seems worthwhile to point out that even on the basis of elasticity theory the difference between the effects of interstitials and vacancies is quite large in the case of the shear moduli. Using Nabarro's effective volume and Bruggeman's equations the calculations give these results: 1 percent interstitials raises the shear modulus by 6.3 percent and 1 percent vacancies decreases the shear modulus by 1.5 percent. The difference would be correspondingly larger if the larger effective volume of the interstitials were used in the calculation. Thus, in the case of the shear moduli, the writer's original estimates are quite conservative and the conclusions remain unchanged.

The writer is grateful to Dr. Nabarro for calling attention to some of the difficulties of the original analysis and for pointing out that an independent estimate can be made based on elasticity theory.

* Under contract with the AEC.
[1] G. J. Dienes, Phys. Rev. **86**, 228 (1952).
[2] F. R. N. Nabarro, preceding letter, Phys. Rev. **87**, 665 (1952).
[3] D. A. G. Bruggeman, Ann. Physik **29**, 160 (1937).
[4] J. K. Mackenzie, Proc. Phys. Soc. (London) **B63**, 1 (1950).

The Response of Sodium Iodide Crystals to High Energy Protons*

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(Received May 14, 1952)

FOR the purpose of analyzing the energy spectrum of high energy protons, a scintillation counter particle spectrometer has been constructed employing thallium activated sodium iodide crystals, as described in the accompanying letter.[1] To make such a device useful for energy determinations, it is necessary to know the relationship between the size of the light flash produced in the crystal and the energy of the particle striking it. Previous studies[2,3] have indicated that this relationship is approximately linear for

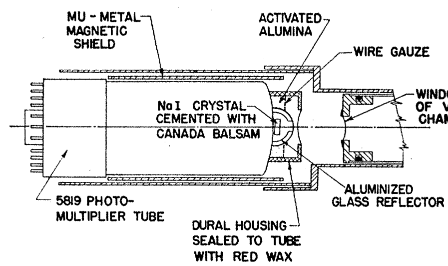

FIG. 1. Mounting of NaI crystal used for studying the response of NaI to high energy protons. Protons scattered by a platinum foil strike the crystal after passing through three aluminum windows and a short air path.

protons incident on sodium iodide. We have re-investigated this question with careful attention to the sources of error that may influence the result obtained.

The sodium iodide crystals employed in this experiment were cleaved from 200-gram ingots purchased from the Harshaw Chemical Company. The cleaving was accomplished in a large vacuum tight metal dry box equipped with airlocks. It was found that freshly cleaved surfaces of sodium iodide can be maintained indefinitely without deterioration in an atmosphere of nitrogen dried by circulation through activated alumina (Al_2O_3).

The method of crystal mounting employed here is illustrated by Fig. 1. Two slots not shown on the diagram are provided for interposing aluminum foils between the exit window of the scattering chamber from which the protons originated and the aluminum foil cover of the dry box surrounding the crystal.

The energy of the external protons from the Princeton cyclotron was determined by measuring their range in aluminum. A differential detector consisting of a single layer of ZnS(Ag) crystals deposited on the face of a 5819 photomultiplier tube was used in this measurement. The average thickness of the crystals was estimated to be equivalent to 4.8 mg/cm^2 aluminum. The observed mean range of 484 ± 5 mg/cm^2 deduced from an integral straggling curve can be interpreted in terms of Smith's range-energy curve or by considering the correction to this curve required by Hubbard and Mackenzie's recent experiment.[6] We have regarded the discrepancy between these two interpretations