lines, and also for studying gamma-ray cascades since the resonant absorption can be observed only for transitions to the ground state of the nucleus. To us it appears possible to use resonant absorption also for investigating a diverse family of shifts and splittings of nuclear levels.* As an example we point out the transverse Doppler effect, the nuclear Zeeman effect,† and the shift in a gravitational field predicted by the general theory of relativity. The investigation of the first two effects is possible in the observation of shifts of the order of 10^{-7} to 10^{-8} ev. As for the shifts in a gravitational field, for a difference of about 10 m in the elevations of source and absorber, the relativistic shift will be about 10^{-15}, which for a quantum energy of 100 kev corresponds to an absolute shift of about 10^{-10} ev.

For observing such small shifts, it is necessary to work under conditions where the natural width of the gamma line is less than the shift being studied or is close to it and where the line is not broadened by incidental effects.‡ Preliminary estimates show, that the latter condition is attainable for a line with a width $\Gamma \sim 10^{-7}$ to 10^{-8} ev, and, perhaps, is attainable for $\Gamma \sim 10^{-10}$ ev, which corresponds to a lifetime of $\sim 10^{-5}$ sec.

Among the known isomeric states of stable nuclei there is one with a fractional width $\Gamma/E \sim 10^{-15}$ — the 92-kev level of Zn^{67} ($\tau = 9.3 \times 10^{-6}$ sec), excited as the result of K capture[4] by 78-hour Ga^{67}. In principle, the 92-kev gamma transition in Zn^{67} can be used for the observation of the above mentioned gravitational effect.**

At the present time, an experimental investigation of the possibilities indicated above by use of the resonant scattering of gamma rays appears to be expedient.

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*As has become known to us, analogous considerations were expressed by W. E. Lamb at the Conference on Quantum Electronics, held 14-16 October, 1959 in the USA, and by Alikhanov.

†We wish to point out, that the use of the nuclear Zeeman effect may afford the possibility of investigating the gamma transitions of polarized nuclei and the interactions with polarized gamma quanta.

‡Examples of such incidental effects are the Doppler broadening due to vibration of the source or absorber, and washed out or split lines due to magnetic or electric fields.

**In experiments it may be convenient to produce a shift of known magnitude with the aid of the Doppler effect (relatively large shifts) or of the nuclear Zeeman effect (small shifts).

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POSSIBLE MAGNETIC EFFECTS FROM HIGH-ALTITUDE EXPLOSIONS OF ATOMIC BOMBS

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LET us consider an atomic explosion at such an altitude that the explosion products expand practically into a vacuum (e.g., an "Argus" explosion at an altitude of 500 km). In the explosion the bomb materials are heated to many ev and thus form a dense plasma, which then expands from the explosion center at the rate of several hundreds of kilometers per second. Thus, the plasma volume will be increased and the ion concentration correspondingly reduced. The expansion of the plasma through the magnetic field will cease as soon as the kinetic pressure of the plasma (or its "head"), which will be falling off as the expansion progresses because of the decrease in ion concentration, equals the magnetic pressure. Because of the diamagnetism of the plasma, the earth's magnetic field will be decreased in the volume occupied by the plasma and if the ion concentration is sufficient, it will be eliminated altogether. For the present purpose, this weakening or elimination of the field inside the plasma can be represented as the result of the establishment within the plasma volume of an effective magnetic dipole whose field within the plasma is opposite to the magnetic field of the earth. Once this effective dipole has appeared, it will create a noticeable magnetic field at great distances from the explosion center, and this field will be registered as the appearance of a magnetic disturbance ("storm") whose leading edge will have a rise time corresponding to the period of plasma expansion. As the plasma expands in the magnetic field, magnetohydrodynamic fluctuations may also be excited.

Besides the magnetic disturbance due to the appearance of a plasma in the vicinity of the explosion, disturbances may exist due to the subsequent movement of the plasma along the field line in a magnetic trap, i.e., in regions remote from the explosion site. The nearest approach of the plasma to the earth should be expected at the magnetic conjugate points or at the extremities of the trap (i.e., at the reflection points) where an increase in plasma concentration can be expected. For these reasons one may expect to find an intensification of the magnetic disturbance at the sub-conjugate points or sub-mirror points and around these.

The effective magnetic moment M of the plasma is equal to

$$M \sim W/H, \tag{1}$$

where W is the energy of the explosion and H is the magnetic field at the explosion point. At the sub-burst point of an explosion occurring at altitude h, the amplitude of magnetic disturbance H′ is

$$H' \sim M/h^3 \sim W/Hh^3 \sim 10^{-26}\, W\,(1 + R_3/h)^3 \tag{2}$$

(10^{26} being the magnetic moment of the earth and R_3 being the earth's radius). For an "Argus" explosion (h = 500 km, W = 10^3 tons = 4.2×10^{19} erg) H′ should be $\sim 100 \times 10^{-5}$ oe. At a distance L from the explosion H′ is

$$H' \sim W/HL^3. \tag{2′}$$

The rise time τ of the leading edge of the magnetic disturbance is equal to the expansion time of the plasma with a mass Q to some final volume V:

$$\tau \sim Q^{1/2}/H^{2/3}W^{1/6}, \text{ sec.} \tag{3}$$

The frequency of the magneto-acoustic oscillations can be determined from the expression

$$\nu \sim r/4c \sim 1/4\tau, \text{ sec}^{-1}. \tag{4}$$

with $c = H/\sqrt{4\pi Q/V}$ as the Alvén speed of the magneto-acoustic wave; $r = (3V/4\pi)^{1/3}$ the characteristic size of the plasma; and $V \simeq 4\pi W/H^2$. The rise time of the leading edge is seen to depend only slightly on the energy of the explosion and increases as the altitude of the explosion is increased. In the case of an "Argus" explosion τ should be ~ 0.5 sec and $\nu \sim 1/2$ sec (where we have substituted in (3) and (4) $Q = 5 \times 10^5$ g, $H = 0.5$ oe, $W = 4 \times 10^{19}$ erg). For explosions at altitudes of 6,000 and 60,000 km, respectively $\tau \simeq 2$ and 50 sec.

Penetration of the earth's magnetic field by individual volumes of plasma from the sun could present a similar picture, since this plasma moves at a rate close to the expansion speed of the explosion plasma. However, these phenomena would probably have their own peculiarities due to the slowing down of the solar plasma at a great distance from the earth.

Should an explosion occur in the polar regions, where the mirror is practically open on one side, the possibility of an effect cannot be ruled out, since the plasma could reach the mirror point situated below the explosion.

Equations (2) and (2′) can be used to evaluate H′ in the region of the conjugate points, once W is replaced by Wk, with k representing the portion of plasma ions reaching the conjugate point. In the case of the mechanism set forth here, it is essential that the rate of expansion of the magnetic disturbance be equal to the speed of light. Disturbances are also possible due to magneto-acoustic oscillations propagating through the ionosphere. The recording of these oscillations should show a lag in conformance with the lower speed of the disturbance (Alvén speed). This fact provides a direct criterion for distinguishing them from disturbances of the type described above. The fields of these disturbances are smaller than the values given by Eq. (2).

Papers recently published[1,2] have indicated that the "Argus" explosions produced periodic magnetic disturbances with a period of 1 – 2 sec.[2] We note that this period is close to the value of 2 sec predicted by Eq. (4). At the sub-burst point the amplitude of the disturbance amounted to 10×10^{-5} oe,[1] rather than 100×10^{-5} oe as predicted by Eq. (2). However, the measurements were made with instruments whose sensitivity was impaired in the region of the measured frequencies, so that the true value of H′ should have been greater than 10×10^{-5} oe.

The values for H′ were measured at distances of from 5,000 to 10,000 km from the explosion (the coordinates of the explosions being –38°/12°WG; –50°/8°WG, and –50°/10°WG). The various measured values of H′ exceed those predicted by Eq. (2′) by 5 to 100 times. It may be that at some stations (e.g., Paris) the recorded disturbance was from a plasma that had moved along a field line toward the conjugate point (the Azores) and that therefore happened to be nearer the observation site when recorded than at the instant of the explosion. Unfortunately, the time service was too crude to permit an accurate comparison of the detection and explosion times.

Another possible reason for the partial enhancement is the influence of geological conditions (electrical conductivity), which as geophysical experience has shown can alter the amplitude of a magnetic disturbance at a recording station by several magnitudes.

The enhancement of the measured magnetic disturbance over the maximum amplitude predicted by the magnetostatic model forces one to seek a different concept of the propagation of the disturbance. Ya. A. Al'pert has suggested that a disturbance propagates in the space between two conductive layers, i.e., the ionosphere and earth. The disturbance therefore is only slightly weakened with distance. It travels from the explosion point to this spherical layer in the form of a magnetohydrodynamic wave in the ionosphere and is propagated along magnetic field lines with slight absorption.

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THE $d + d \to \pi^0 + He^4$ REACTION AT 400 Mev DEUTERON ENERGY

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Up till now all experimental investigations in testing the principle of charge invariance in the formation process of π mesons were carried out by comparing two charges of coupled reactions, the cross sections of which have to be in a given relation while preserving the full isotopic spin. This refers to the reactions $p + p \to d + \pi^+$ and $n + p \to d + \pi^0$, which were investigated at 400 and 600 Mev, and also to the reactions $p + d \to t + \pi^+$ and $p + d \to He^3 + \pi^0$, which were compared at 340,[5] 450,[6] and 600 Mev.[7]

However, a more direct method of checking the principle of charge invariance, which is free from any systematic errors, consists of establishing the degree of forbidenness as a consequence of the preservation of the isotopic spin in the process of meson formation. Thus, for instance, forbidenness due to this principle should take place in the reaction[8]

$$d + d \to \pi^0 + He^4. \qquad (1)$$

By this process it is also possible to check the hypothesis, advanced by Baldin,[9] of the existence of the isotopically scalar π^0 mesons, to eliminate the contradiction between the data covering the photoproduction of π mesons near threshold and the Panofsky relation.

A description follows here of the first data of the reaction (1), obtained in the synchrocyclotron of the Joint Institute for Nuclear Research at 400 Mev deuteron energy. The measurements were made with an extracted beam of deuterons having an intensity of about $3 \times 10^{10}\ sec^{-1}$. The secondary charged particles formed in the targets of heavy polyethylene and carbon were separated by a brass collimator placed at an angle of 5.6° to the deuteron beam, were deflected by a magnetic field at an angle of 27°, and passed through a steel collimator in the shielding concrete wall. They were then recorded by a telescope consisting of six scintillator counters. The identification of the charged particles knocked out of the target was carried out by effective momentum, specific ionization, and range. The separation of particles with a given momentum was carried out with the aid of an electromagnet, the poles of which had been given a special shape to improve resolving power. The separation of the particles with regard to the extent of the specific ionization was made independently in each of the five telescope counters. This method[10] made it possible to separate reliably the rare processes of the emission of particles with a high degree of ionization against the background of the extraneous radiation of lower ionization. The particle range was determined by retarding filters, which were arranged before the fifth and the sixth telescope counter, the latter being connected in anticoincidence with the first five so as to separate the particles in the given range interval. In the first five telescope counters scintillators were used with foils 0.5 mm thick, which enabled the recording of the α particles starting with 60 Mev energy. The discriminator scale was calibrated in a beam of α particles at 800, 700, 460, and 370 Mev. The general control of the apparatus and the calibration of the electromagnet scale were carried out by recording the He^3