the vibration of specific boron atoms or to vibrations of certain atom groups cannot yet be stated.

As can be seen from Fig. 2, the transmission of boron decreases strongly for wavelengths smaller than approximately 2 μ. A plot of the calculated absorption coefficient as a function of photon energy indicates that two absorption mechanisms are present. The absorption rises rapidly with increasing energy for $h\nu > 1.2$ ev. This sharp rise is considered to correspond to optical transitions across the forbidden energy gap. For 0.6 ev $\leq h\nu \leq 1.2$ ev, the absorption increases less rapidly with the photon energy. Several possible causes may be cited for this latter absorption: transitions to or from states within the forbidden gap, interband transitions arising from a complicated band structure, scattering effects due to lattice imperfections. A more detailed study of these questions is in progress.

We wish to acknowledge the aid of J. A. Gutowski who prepared some of the specimens for the measurements and G. Sorin who helped in taking some of the infrared data.

---

[1] Hoard, Geller, and Hughes, J. Chem. Soc. 73, 1892 (1951); D. E. Sands and J. L. Hoard, J. Chem. Soc. 79, 5582 (1957); B. F. Decker and J. S. Kasper, American Crystallographic Association, Milwaukee, Wisconsin, June, 1958 (unpublished).

[2] E. S. Greiner and J. A. Gutowski, J. Appl. Phys. 28, 1364 (1957); see also Shaw, Hudson, and Danielson, Phys. Rev. 107, 419 (1957).

[3] J. Lagrenaudie, J. chim. physique 50, 629 (1953); T. S. Moss, Photoconductivity in the Elements (Butterworths Publications, London, 1952); N. Morita, J. Sci. Research Inst. 48, 8 (1954).

[4] W. G. Spitzer and H. Y. Fan, Phys. Rev. 99, 1893 (1955); H. Yoshinaza and R. A. Oetjer, Phys. Rev. 101, 526 (1956); Picus, Burstein, and Henvis, Bull. Am. Phys. Soc. Ser. II, 2, 66 (1957).

BROKEN ATOMIC BEAM RESONANCE EXPERIMENT[*]

Daniel Kleppner, Norman F. Ramsey,
and Paul Fjelstadt
Lyman Physics Laboratory,
Harvard University,
Cambridge, Massachusetts

(Received August 18, 1958)

All past atomic beam resonance experiments have been limited to cases in which the atoms undergo no collisions between the source and the detector. However, several years ago Ramsey[1,2] pointed out that the separated oscillatory field resonance method[3] in principle could be extended to cases in which the atoms in the beam were subject to collisions either with other atoms or with suitable solid surfaces in the region between the two oscillatory fields. It was pointed out[2] that such experiments not only would provide information on the nature of the collisions but also might make possible resonance experiments of unprecedented accuracy if the atoms could be stored for considerable lengths of time in a box with suitable surfaces.

It is the purpose of the present note to point out the first success of such a broken atomic beam experiment. The arrangement of the apparatus for the experiment was as shown in Fig. 1. Cesium atoms from a heated oven emerged into a six-pole deflecting magnetic field[4] region from which only the atoms in the hyperfine state $F = 4$ could emerge. The atoms then entered the first oscillatory field region followed by a small box of such a configuration that no atom could pass through the box without undergoing at least two wall collisions. The atoms then entered the second oscillatory field region which was followed in turn by another six-pole deflecting magnetic field through which only $F = 4$ atoms could pass. The characteristic Ramsey separated oscillatory field resonance pattern[3] was then sought corresponding to atomic transitions between the $F = 4$, $M = 0$ and $F = 3$, $M = 0$ state.

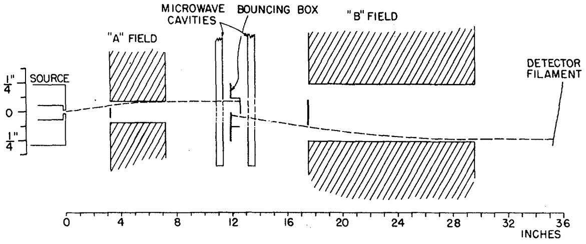

FIG. 1. Experimental arrangement of the broken atomic beam.

The first box tried possessed walls of unheated teflon. With these no Ramsey pattern could be observed in the emerging beam, though a pattern corresponding to transitions in a single microwave cavity was observed. However, when the box was heated to 100°C the characteristic Ramsey pattern was observed, despite the fact that the atoms of the beam had to undergo at least two collisions between the oscillatory fields. The observed intensity of the resonance corresponded to about 15% of the intensity of the beam emerging from the box. Surfaces of unheated eicosane and polyethylene have also been tried. Both gave Ramsey curves of a size comparable to that of heated teflon. At present we are trying to determine whether the small size of the Ramsey pattern truly represents relaxation of the atoms on the walls or is due to some experimental difficulty. It is suspected that the power levels in the microwave cavities may not have been their optimal values.

The only reported experiment closely related to the present one is the recent successive oscillatory fields experiment of Robinson, Ensberg, and Dehmelt[5] which was based on another aspect of Ramsey's proposal.[1,2] However, Dehmelt's experiments were limited to low-frequency transitions between states which differed only in magnetic quantum number. The experiments in the present report are the first wall collision resonance experiments involving high-frequency transitions between states of different hyperfine F values as well as the first resonance experiments of any kind with the broken atomic beam resonance method. The present resonance experiments are more distantly related to the nonresonance wall bounce experiments of Hawkins[6] and the spin relaxation experiments of Robinson, Ensberg, and Dehmelt.[5]

At present, an extensive program for testing different collision surfaces is being initiated in the hopes of finding a suitable surface for a high precision atomic clock incorporating both the storage box[1,2] and maser principles.[7]

The authors wish to thank J. T. LaTourrette, W. A. Hardy, S. M. Gardner and the other members of the Harvard Molecular Beam Laboratory for their help in this experiment.

---

[*] This work was supported by the Signal Corps and by the joint program of the Office of Naval Research and the U.S. Atomic Energy Commission.

[1] N. F. Ramsey, Proceedings of the Frequency Standards Conference, Ft. Monmouth, New Jersey, February, 1956 (unpublished).

[2] N. F. Ramsey, Rev. Sci. Instr. 28, 58 (1957).

[3] N. F. Ramsey, Phys. Rev. 78, 695 (1950).

[4] H. Friedburg and W. Paul, Naturwissenschaften 38, 159 (1951).

[5] Robinson, Ensberg and Dehmelt, Bull. Am. Phys. Soc. Ser. II, 3, 9 (1958).

[6] B. Hawkins, Proceedings of the Frequency Standards Conference, Ft. Monmouth, New Jersey, April, 1957 (unpublished).

[7] Gordon, Zeiger, and Townes, Phys. Rev. 99, 1264 (1955).

PIEZOELECTRIC EFFECT IN INDIUM ANTIMONIDE*

J. H. Wasilik and R. B. Flippen†

National Bureau of Standards,
Washington, D. C.

(Received August 7, 1958)

It is expected that crystals of the zinc blende structure will be piezoelectric, since the lattice lacks a center of symmetry. The ionic character of InSb has been indicated by several authors[1-3] to be in the range of 10-20% of the total available charge.

We have made qualitative observations of piezoelectric resonances at the first and third harmonics of thickness vibrations in two InSb plates. Because of the relatively high conductivity (~200/ohm cm) of InSb at room temperature which would effectively short out the piezoelectric voltage, measurements were taken at 78°K and 4.2°K where the resistances of the samples were large.[4] The plates, 0.71 and 1.02 mm thick and 5 mm square, were cut normal to the [111] direction, and their faces ground parallel within a few hundredths of a mm. The plates were then etched and their large flat surfaces plated with rhodium; thin copper leads were indium-soldered to the corners of the plated sides. The plates were then mounted in a vacuum to reduce acoustic losses. One sample had a p-n junction in the plane of the plate and, as suggested by Burstein,[5] such a sample should be suited for a qualitative observation of a piezoelectric effect, having a relatively high resistance, even at liquid nitrogen temperatures. The other sample (from an adjacent slice) was high-resistivity p-type ($\sim 1.4 \times 10^3$ ohm-cm at liquid helium temperature). In both samples the effect was detected as a slight drop in voltage across the plate when the frequency of the driving oscillator (loosely coupled to the sample) was tuned through one of the resonant modes of the plate. The voltage change was observed as a departure from a null condition in a voltage compensation circuit. The calculated and observed resonance frequencies for the two plates are given in Table I. The effect was detected in the p-n junction plate at both liquid nitrogen and liquid helium temperatures at the same frequencies. In the p-type plate it could be detected only at 4.2°K.

As is characteristic of vibrating plates, the thickness modes are coupled to numerous other modes of vibration, flexure, face shear, etc., resulting in a number of resonances grouped