than sufficient heat would be generated in a mantle having a uniform potassium content equivalent to that of stony meteorites[4]. In either case, however, we have the paradox that if the mantle under the continents is similar to that under the ocean, then the heat flow from the continents should be much higher than the observed value because of the presence of highly radioactive rocks in the outer parts of the continental crust.

A heat flow of $1 \cdot 2 \times 10^{-6}$ cal. cm.$^{-2}$ sec.$^{-1}$ through the ocean floor should noticeably heat the bottom-water masses as they flow northward from the Antarctic. With a velocity of northward flow of the order of $0 \cdot 1$ cm. per sec., as suggested by Sverdrup, Johnson and Fleming[5], the temperature of a layer of bottom water 1 km. thick would increase by about one-tenth of a degree centigrade on its journey from the region of sinking in the Antarctic to the tropics. This amount of heating would be largely masked by mixing with high-temperature water from above. But with the much smaller velocity of northward flow suggested by some recent workers, there should be a much larger increase in the bottom-water temperature between the Antarctic and low latitudes. Such an increase is not observed. The possibility exists, therefore, that our measurements are not representative of the heat flow through the sea floor. Obviously many more measurements must be taken before reliable generalizations can be made.

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[4] Birch, F., *J. Geophys. Research*, **56**, 107 (1951).
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THE preceding communication by Revelle and Maxwell gives a result which is completely unexpected, and demonstrates again how little we know of submarine geology. Their observations do, I believe, demonstrate that the heat flow is roughly the same under the oceans and continents. It seems most unlikely that this is a temporary condition dependent on recent large changes in the temperature of the bottom water, for this is largely determined by the existence of ice in the Arctic and Antarctic. The ice cannot have melted since the last ice age, because the water from it would drown the greater part of the continents. It seems almost certain that the heat found by Revelle and Maxwell must be generated by radioactivity in the rocks beneath the oceans, and therefore that the total amount of radioactivity beneath unit area of continent and ocean is the same when summed down to a depth of a few hundred kilometres (heat generated deeper down has not had time to escape). This would be very surprising if the continents were formed from a primitive sialic layer not present under the oceans, and are underlain by material which is the same under continents and oceans. It would, however, be natural if the continents are continuously expanding by a process of differentiation in which radioactive material is concentrated vertically[1]. The rocks beneath the oceans would then have the same total amount of radioactivity as those beneath the continents, but spread through a greater range of depth; this would give the same heat flow as beneath the continents, but higher temperatures at depth.

As is pointed out by Revelle and Maxwell, some upward concentration is necessary to avoid melting under the oceans. Calculation suggests that if the radioactivity were spread through a depth of 150 km., no impossibly high temperatures would be produced. A possible interpretation of the results therefore appears to be that when the earth solidified most of the radioactivity was concentrated in the upper 150 km. of the mantle; under the oceans this distribution still exists, but under the continents a further concentration has occurred into the top 10 or 20 km. On this view it would be expected that the oceanic ultra-basic rocks would contain more radioactive material than the continental ones. There are few reliable measurements; but those that do exist do not show such a difference. This matter should be further investigated.

Other explanations can be suggested. It might, for example, be supposed that at some not too remote time a convection current rose under the Pacific and brought hot material near the surface, or that the horizontal limb of a convection current had transported material from beneath the continents to the central Pacific. Such suggestions are pure speculation, and there is no other evidence in their favour.

The difficulties may be connected with that of reconciling the oceanic seismic and gravity results. The gravity results suggest that the material beneath the Mohorovičić discontinuity may not be quite the same beneath the continents and oceans in spite of the close agreement in seismic velocities. Some discussion of these matters is given in a book[2] to be published shortly.

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Use of a Gamma-Ray Pinhole Camera for *in vivo* Studies

THE pinhole camera method of taking gamma-radioautographs, though it has been described in the literature[1], has had very little use because of the long exposure times which are necessary even when the most sensitive radiographic films are used. An intensifying screen for use with the pinhole camera has now been developed which has made it possible to reduce the exposure time considerably. The screen consists of a large, flat crystal of thallium-activated sodium iodide. The gamma-rays produce scintillations in the crystal which in turn affect the photographic plate. This method has made it possible to take an *in vivo* gamma-ray pinhole radioautograph of a tumour containing 20 millicuries of iodine-131.

A drawing of the pinhole camera and intensifying screen is shown in Fig. 1. A gamma-ray from the object being photographed goes through the pinhole and travels in a straight line until it enters the sodium iodide crystal, where it may produce a Compton or photoelectric recoil. The recoil electron travels about a millimetre or less in the crystal. The light

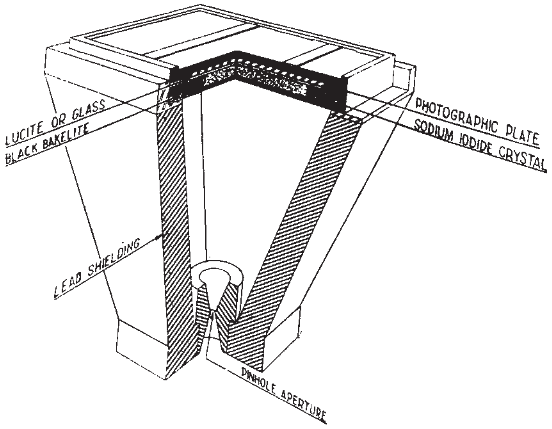


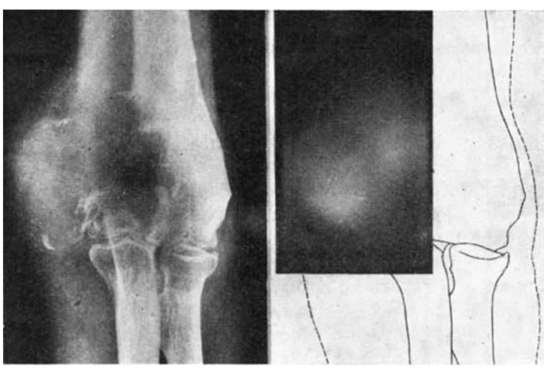
Fig. 1

produced along the path of the recoil is emitted isotropically. The spreading of the light over the photographic plate and the consequent loss of definition are limited both by inverse square law attenuation and by total reflexion from the glass-to-air boundary between the crystal and photographic plate. The angle of total reflexion is about 35°. The light reflected from the glass surface passes back through the crystal and is absorbed by the black 'Bakelite' container.

There is a considerable loss in definition due to spreading of the light from the thick intensifying screen, even though it is limited as described above. In ordinary radiographic work this would not be permissible; but due to the relatively poor definition obtained from the pinhole camera, the additional loss in definition is relatively unimportant. In order to get good optical contact between the crystal and the glass window, and also to protect the crystal from the effects of moist air, it is contained in a bath of Monsanto Chemical Co. 'Aroclor No. 1248'.

The camera was tested by taking autoradiographs of bottles of iodine-131 solution. It was found that a concentration of about 1 mC./cm.^{2} and an exposure time of 1 hr. were sufficient to give a faint but usable image of the source. This is about twenty times less exposure time than is necessary if Kodak No-Screen film is used with the lead-foil intensifying screens customarily used for gamma-ray radiographs.

The exposure times given above are for the following conditions. The pinhole size was 1/8 in.; the pinhole-to-intensifying screen distance $7\frac{1}{2}$ in.; the intensifying screen was a crystal of thallium-activated



(a) X-ray radiograph. (b) Pinhole autoradiograph

Fig. 2. Metastasis of thyroid tumour at elbow

sodium iodide crystal 2 in. × 4 in. × 5/16 in. thick, obtained from the Harshaw Chemical Co., 1945 East 97th Street, Cleveland 6, Ohio; the photographic plate was a Kodak type 103a—0 spectroscopic plate slightly overdeveloped in *D*-19 developer.

As mentioned before, the camera has been used for taking an *in vivo* gamma-ray autoradiograph of a tumour containing iodine-131. The tumour was a metastasis of a thyroid carcinoma. It was close to the skin, had a volume of 90 ml. and an area of about 20 sq. cm. The picture was taken 24 hr. after a therapeutic dose of 100 mC. iodine-131 was administered to the patient. It was determined independently that 20 mC. lodged in the tumour. A one-hour exposure was taken and the resulting picture is shown in Fig. 2*b*. The general outline of the area which took up the iodine-131 is shown, together with the fact that it is concentrated in two main areas. An X-ray radiograph of the tumour taken from the same point of view is shown in Fig. 2*a*.

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Microradiography with Alpha-Rays

Alpha-particles are very strongly absorbed even by thin layers of materials. Their path through matter is almost exactly a straight line, and their effect on a photographic emulsion is very strong. These properties seem to be well suited for microradiographic mass determinations. Since such methods promise to be of value in several research fields, such as biology, medicine, mineralogy and metallurgy, experiments have been undertaken to determine the potentialities and optimal conditions for alpha-microradiography. The main advantage of using alpha-particles as compared with soft X-rays[1] would be the much simpler apparatus needed and the relative independence of the absorption on the composition of the object.

From purely geometrical considerations it is evident that to obtain high picture-resolution the alpha-particles must be collimated to normal incidence upon the object. Further, the object must be placed as near as possible to the photographic emulsion, and the grain-size of the emulsion should be small enough to allow the necessary enlargement. The collimation is most simply accomplished as in other types of radiography; the source of alpha-rays is placed at a distance from the object, which is large compared with the size of the source and the object.

When arranging for optimal mass resolution, that is, good contrast between areas differing in mass per unit area, the special mechanism of alpha-absorption must be borne in mind. The alpha-particles, being fast helium ions, are gradually slowed down