sharper. At the same time, the violet band changes somewhat in shape, and maximum absorption shifts from 450 to 423 $m\mu$. These changes are probably the result of unfavorable growth conditions or autolysis. An attempt to separate the various pigments involved and to investigate their nature is now in progress.

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Production of Radioactive Organic Compounds with Recoil Tritons

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THE methods that have been widely used for the introduction of radioactivity into molecules are chemical synthesis, biosynthesis, and isotopic exchange. Even when these methods are feasible, they are often costly and time-consuming, and the need has been felt for a more direct technique. Exploitation of the momentum properties of nuclei formed in nuclear events offers the possibility of such a technique through incorporation of radioactive recoil atoms into previously inactive molecules. In this paper (*1*) a method is proposed that appears to be generally useful for the direct labeling of organic compounds by means of recoil tritons.

When a nuclear transformation occurs the emission of a particle or γ-ray usually gives the resulting species a recoil momentum that is very large in chemical terms. Such recoil or "hot" atoms, often having an energy of many thousands of electron volts, usually break the bonds attaching them to the parent molecules and in a condensed medium travel for at least several atom diameters before being reduced to thermal energy. During this journey they have sufficient energy to break bonds and they may then combine chemically with one of the fragments produced (*2–4*). If the hot atom is radioactive, a tagged molecule will then have been formed. In general it is likely that the new molecule will be a degradation product of the parent species.

The recoil behavior of radioactive halogen atoms following neutron capture in organic solutions has been extensively investigated (*2, 4*). Depending on the nature of the parent compound, a large number of radioactive species may be formed, most of which can be considered degradation products of the original molecule. A number of experimenters have shown that the $N^{14}(n,p)C^{14}$ reaction carried out in nitrogen containing organic compounds (*5, 6*) results in the production of many C^{14}-labeled organic compounds, although only a small fraction of the activity is to be found in the original compound irradiated. For instance Wolf and Anderson (*6*) made a careful investigation of the acridine case and found that only about 3 percent of the C^{14} formed was retained in the parent compound.

Schrodt and Libby have recently produced radioactive aliphatic hydrocarbons by dissolving nitrogen compounds in them and irradiating the solution in the pile (*7*). Using normal pentane, 25 percent of the total C^{14} produced was found to be in the form of labeled *n*-pentane. This method thus seems to be of considerable promise for the production of tagged compounds in those cases where a homogeneous nitrogen-containing system can be prepared. The technique appears, however, to be considerably less efficient for cyclic compounds.

Tritium and C^{14} are the only radioactive isotopes that are generally useful for tagging organic compounds. The use of tritons rather than C^{14} recoils may be expected to have several important points in its favor. The number of recoil atoms that can be introduced into an organic compound is usually limited by the amount of radiation the system can withstand before being destroyed. Thus the 12.5-yr half-life of tritium is distinctly more convenient than the 5600-yr half-life of C^{14}, since for a given number of radioactive atoms the specific activity of a labeled compound will be 450 times higher for tritium than it will be for C^{14}. Moreover, recoil tritons need break only a single bond and displace a single proton to be incorporated in the compound to be labeled; in the analogous case of C^{14}, several bonds must be broken, and in most cases the carbon skeleton of the compound must be disrupted to admit the tracer atoms. It therefore seems reasonable—especially for complex compounds—that the introduction of recoil tritium is less likely to result in degradation of the parent compound.

Studies of hot-atom chemistry have been limited to homogeneous systems because of the short range of the recoil atoms involved. Tritons, however, are exceptional because, unlike other recoil atoms produced in common nuclear reactions, they have a range measured in microns rather than angstroms. Thus the tritons from neutron-bombarded Li^6 have a range of approximately 50 μ ($\sim$5 mg/cm^2) in organic materials. This presents the interesting possibility of using heterogeneous systems to study the hot-atom chemistry of tritium and to produce activated molecules. In a reasonably finely divided mixture the tritium created in one phase can recoil out of it and into a neighboring phase, where it can undergo hot-chemical reactions with the production of radioactive molecules. For convenience we may call these processes "heterogeneous hot-atom chemistry" and "heterogeneous recoil tagging." The possibility of using heterogeneous as well as homogeneous systems gives an additional and very important advantage to tritium methods of recoil tagging. While a suitable homogeneous system for irradiation is often difficult to find or hard to prepare, a heterogeneous system is always readily available.

The reaction $Li^6(n,\alpha)T$ is convenient for this purpose because it has a slow neutron cross-section of 910 barns for an isotope occurring in 7.5-percent natural abundance. This yield, together with the shorter half-life of tritium, makes it possible to use conveniently short irradiations.

A mixture of Li_2CO_3 and glucose was chosen to test these ideas. The system for irradiation was prepared by grinding together equal amounts with a pestle and mortar. (The 1-μ particles thus produced were actually much smaller than is necessary.) A preliminary run with a glucose-Li_2CO_3 mixture showed that a significant fraction of the radioactivity followed glucose through paper chromatography.

In a second run a 160-g sample, spread over an area of 200 cm^2 to minimize self-shadowing, was exposed to a neutron flux of 6×10^9 neutrons/cm^2 sec. At the end of the 65-hr irradiation the mixture was slightly brownish from radiation decomposition.

Table 1. Counting rates from successive recrystallizations of glucose pentaacetate.

Sample	Weight (mg)	Counts/min	Counts/min mg
GPA-1	7.48	23,000	3080
	5.94	18,700	3150
GPA-2	9.24	28,980	3150
GPA-3	5.86	17,960	3060
GPA-4	6.28	19,690	3140
GPA-5	13.16	41,000	3120

Glucose was separated from Li_2CO_3 by hot water extraction and absorption on Amberlite 120-IR resin. Organic acids were removed on Duolite-A-4 (hydroxide form) resin. The solution was decolorized with Darco 60 charcoal, concentrated to a syrup, diluted with methyl alcohol, reconcentrated and seeded with glucose crystals. After filtration, the precipitate was triturated with methyl alcohol, filtered, washed with methyl alcohol, and dried. The glucose was then converted to glucose pentaacetate and recrystallized five times from ethyl alcohol-water solution. Aliquots from each fraction were counted internally in a Geiger flow counter as infinitely thick solids. Several samples were converted to gas and counted by the technique of Wilzbach, Kaplan, and Brown (*8*). The constant specific activity through five recrystallizations, as shown in Table 1, indicates the absence of radioactive impurities in the glucose pentaacetate.

From the known neutron flux and cross-section values, we conclude that approximately 10 percent of the tritons stopped in the organic phase had been incorporated into glucose in nonlabile positions. Any tritium originally substituted into the hydroxyl positions would have been removed during purification. The specific activity of glucose obtained in this run was 3μc/g of glucose.

In general, the limits of specific activity attainable will depend on the stability of the particular compound toward radiation decomposition. Although glucose appears to be exceptionally susceptible to radiation damage, preliminary results of further experiments indicate that specific activities 100 times greater than that we report are possible. In more favorable cases, irradiations of a few days in fluxes of 10^{12} to 10^{13} neutrons/cm^2 sec could produce specific activities of the order of millicuries per gram.

L. Kaplan at Argonne National Laboratory has carried out an independent check of our technique using Li_2SO_4 and benzoic acid. With a precise measurement of the neutron flux it was determined that 25 percent of all the tritons produced resulted in benzoic acid labeled in the ring hydrogens. An activity of 96 μc/g of benzoic acid was obtained with little radiation decomposition (*9*). This experiment demonstrates that the method is applicable to cyclic systems.

From this experimental evidence it would appear that heterogeneous recoil tagging should be generally useful for making tritium-labeled organic compounds of good specific activity. The type of system used in the experiments quoted—a powdered mixture—is by no means the only one that may be used. Presumably a slurry or emulsion containing an organic and a lithiated phase should work provided that the particle size was not much larger than the recoil range.

Although preparation of the labeled material is not difficult, its purification is complicated by radiation damage. Many of the molecules activated by the recoil tritons may be slightly altered by them to produce highly radioactive trace materials, chemically similar to the parent compound. In the purification process, useful quantities of these species may be separated.

An obvious limitation of the technique proposed here is that it cannot produce the very high specific activities obtainable by chemical synthesis or exchange with materials containing large percentages of radioactive atoms. A further and probably more serious drawback is that in general it will not be possible to produce compounds labeled at specific positions. As a first approximation it is to be expected that recoil tritons will produce random labeling. This will also result in some of the tritium being held as labile atoms. However all such loosely bound tracer can be washed out in the purification.

The practical limits of this technique have yet to be ascertained. Since larger molecules are usually more susceptible to damage by radiation, it is quite possible that with high-molecular-weight compounds only low specific activities will be obtainable. Further study is required for a better understanding of the mechanisms involved in these phenomena.

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Charles Manning Child

By his life and works Charles Manning Child added further distinction to the distinguished New England family name of Manning. He early showed a predilection for the philosophic aspects of biology. After completing the master's degree at Wesleyan University, he went to the University of Leipzig with the intention of studying under Wundt. However, he soon became dissatisfied with the type of study offered and transferred to the zoology department, where he was granted the doctor's degree under Leuckart in 1894. Surprisingly enough, his doctoral research was purely morphological and histological; it was concerned with certain sense organs of the Diptera.

Returning to the United States, Child became a prominent member of that brilliant group of American embryologists who devoted themselves in the 1890's to the subject of cell lineage and produced a series of imperishable articles. Here Child already revealed his trend toward organicism, for he rejected the implications of the mosaic theory of development that had been derived from cell-lineage studies and joined Whitman in his stand against cellular explanations of development.

About 1900 Child began the long series of experiments on the regeneration of coelenterates and flatworms that was to endure through much of his career. He constantly sought for some governing factor in regeneration. At first he believed that this factor was mechanical and ascribed morphogenetic control to such matters as tension, pressure, locomotory activity of the regenerating piece, and the like; reconstitution was believed to result from the attempt of a regenerating piece to function like the whole. On this basis Child published in 1910 a classical article, "The regulatory processes in organisms," in which he pointed out that the continuity of organic individuality is dependent on physiological correlation. This article was the prelude to the emergence of the gradient theory about 1911.

The gradient theory was based on the results of a long accumulation of experiments on the regeneration of planarians. These experiments led Child to abandon his theory of mechanical control of morphogenesis and to concentrate on a physiological gradation of processes as the controlling factor. The essence of the gradient theory is that a gradation of physiological processes forms the basis of polarity and sym-