centrations of the $Rh^{102}$ tracer in surface air. One might therefore be tempted to attribute the increase to this source alone were it not for the debris from Hardtack I, labeled with $W^{181,185}$ and still present in measurable amount, which clearly shows a twofold rise in April through June 1960.

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## Latitudinal Effect in the Transfer of Radiocarbon from Stratosphere to Troposphere

*Abstract.* Latitudinal variations in the descent of bomb-produced radiocarbon from the stratosphere is suggested by differences in tropospheric carbon-14 activity. The magnitude of a similar latitudinal effect in the pre-bomb steady state is estimated. This effect may be part of the explanation of the short-term oscillations in carbon-14 activity found in tree-rings from the last 1300 years.

Several investigators have reported on the bomb-produced rise in the $C^{14}/C^{12}$ ratio of tropospheric $CO_2$ from the Northern Hemisphere (*1–5*). From 1955 and up to the summer of 1957 an annual linear increase of approximately 5 percent was indicated at all stations. From 1957 the rate of increase showed marked differences at various localities in the Northern Hemisphere. The highest tropospheric $C^{14}/C^{12}$ ratios so far reported were derived from a series of Danish cereals (*4*) which were collected from 1956–59 (latitude 56°N, longitude 12°E).

Comprehensive measurements of the increase in tropospheric $C^{14}/C^{12}$ ratios have been made by Broecker and Walton (*2*) and Broecker and Olson (*5*). The annual rate of increase was here derived from plant material and from atmospheric $CO_2$ collected at stations scattered over the United States and over the North Atlantic Ocean at latitudes from 25° to 41°N, and at longitudes from 30° to 120°W. Their values may be considered as close to the average values for the Northern Hemisphere.

The increases in $C^{14}$ activity attained in the two series by 1 July in the years 1956–59 are listed in Table 1. The activities are expressed in $\Delta C^{14}$ units (*6*), that is, approximately the permillage difference from the age-corrected activity of 19th-century wood.

In 1958 the $C^{14}/C^{12}$ ratio at Copenhagen was 37 per mil higher than the supposed hemispheric average measured in the United States and over the North Atlantic, while in 1959 this difference had risen to 63 per mil. As late as 12 October 1959 the $C^{14}/C^{12}$ ratio in atmospheric $CO_2$ collected at Alpine, New Jersey (U.S.A.), was not higher than $\Delta C^{14} = 246 \pm 6$ per mil (*5*).

The higher $C^{14}/C^{12}$ ratio in northern latitudes in Europe in 1959 was confirmed by measurements of cereals from Cambridge (latitude 52°N, longitude 0°). The $C^{14}/C^{12}$ ratio in the summer of 1959 was measured here to 31.8 ± 0.7 percent above the 1953 ratio (*3*). Assuming a similar Suess effect and isotopic fractionation as for the Danish cereals, this corresponds to a $\Delta C^{14}$ value of approximately 298 per mil.

The differences indicate that the dominant descent of bomb-generated $C^{14}$ from the stratosphere took place in locations situated closer to Copenhagen and Cambridge than to the United States and the North Atlantic south of 41°N. Although it cannot be excluded that part of the differences are due to different distances from the test sites located in high northern latitudes, the most probable explanation is latitudinal variations in the descent of $CO_2$ from the stratosphere (*4*). These variations are presumably caused by a selective downward mixing from the stratosphere in middle latitudes by way of the gap in the tropopause (*7, 8*).

The comparatively large additional increase in $C^{14}$ activity at Copenhagen above the hemispheric average, together with the low activity found in atmospheric $CO_2$ over the United States as late as October 1959, suggests that the higher $C^{14}$ concentration can only prevail in a narrow belt or during short time periods. This is in keeping with suggestions of strong seasonal variations for both particulate fallout (*7*) and for $C^{14}$ (*9*).

Latitudinal variations may likewise have occurred in the pre-bomb steady state. The magnitude of such an effect can be estimated from the net transfers of $C^{14}$ atoms from the stratosphere to the troposphere, if it is supposed that the relative distribution of $C^{14}$ atoms in the lower stratosphere was similar in the pre-bomb state and in 1958 and 1959.

Table 1. Carbon-14 content of Danish cereals (*4*) and average $C^{14}$ content in samples from the United States and in atmospheric $CO_2$ over the North Atlantic by 1 July of each year (*5*), in $\Delta C^{14}$ units (per mil).

| Year | Copenhagen (56°N) | U.S. and North Atlantic (25°–41°N) | Difference |
|---|---|---|---|
| 1956 | 39 ± 8 | 30 | 9 |
| 1957 | 89 ± 7 | 80 | 9 |
| 1958 | 172 ± 7 | 135 | 37 |
| 1959 | 308 ± 6 | 245 | 63 |

In the pre-bomb state an excess of approximately $10^{26}$ atoms of $C^{14}$ was annually transferred from the stratosphere to the troposphere of each hemisphere. From July 1957 to July 1958 the net transfer to the troposphere of the Northern Hemisphere was $10^{26}$ atoms plus the number of transferred artificial $C^{14}$ atoms. This last figure may be evaluated to $7 \times 10^{26}$ atoms on the basis of the measured rise of 5 percent in tropospheric $C^{14}$ activity. The total net transfer during this period thus becomes $8 \times 10^{26}$ atoms of $C^{14}$. From July 1958 to July 1959 the total net transfer of $C^{14}$ atoms to the troposphere of the Northern Hemisphere is evaluated from the 11 percent (5) rise in $C^{14}$ activity to a total of $16 \times 10^{26}$ atoms.

Assuming that the magnitude of the latitudinal effect is proportional to the net transfer of $C^{14}$ atoms from stratosphere to troposphere, and using the 1958 values of 37 per mil difference and a net transfer of $8 \times 10^{26}$ atoms, the pre-bomb steady state latitudinal effect is calculated to 5 per mil. Using the 1959 values of a difference of 63 per mil and a net transfer of $16 \times 10^{26}$ atoms of $C^{14}$, the pre-bomb latitudinal effect is calculated to 4 per mil.

Since a fraction of the bomb-produced $C^{14}$ is added directly to the troposphere and, therefore, may not contribute to a latitudinal effect in plant material—or may even tend to counterbalance it—the above estimates are rather lower limits. It is not known, moreover, whether the $C^{14}$ concentrations measured in Copenhagen represent the peak values for the hemisphere. In view of this, the most likely range for the magnitude of a latitudinal effect in the steady state distribution of the natural radiocarbon in 5 to 10 per mil.

The same magnitude is suggested with another way of estimating: $10^{26}$ atoms of $C^{14}$ are annually produced by cosmic rays in the stratosphere of the Northern Hemisphere. Approximately 75 percent of these atoms are produced in the lower stratosphere north of 45°N.

If, within a few months during the spring, two-thirds of the 75 percent ($0.5 \times 10^{26}$ atoms) are mixed into a belt of the troposphere (for example, 45° to 60°N) containing $3 \times 10^{27}$ atoms, and if the time constant for growth of concentration is roughly equal to the time constant for leakage out of the belt, an average rise in $C^{14}$ concentration of 5 per mil is temporarily produced in the belt, and the peak concentration may attain a somewhat higher value.

Slightly elevated $C^{14}$ concentrations, attributable to a latitudinal effect, may thus have prevailed in a belt around middle latitudes, at least during a period of the year. If the geographic position of this belt is closely related to the position of the tropopause gap or gaps, the belt has had a rather irregular course around the hemisphere.

With changing climates the position of the belt of elevated $C^{14}$ concentration may have shifted in the past after shifts in the position of the tropopause gap. At fixed locations in middle latitudes such shifts will produce oscillations in the $C^{14}$ activity of plant material. This may be part of the explanation of the rather sudden variations in $C^{14}$ activity traced in tree-rings from the last 1300 years (*10, 11*). The $C^{14}$ activity of tree-rings has been found to vary both with time and with location on the earth. The variations with time appear to be composed of short-term oscillations of 1 to 2 percent superimposed upon an oscillation having a longer period (*11*). The variations with location are up to 1 percent (*10*). The oscillations seem to be correlated with climatic phenomena.

Latitudinal variations as estimated above may have contributed substantially to the short-term oscillations in the $C^{14}$ activity of the tree-rings, and in addition may account for the minor differences found in the $C^{14}$ activity of plant material from different locations. Changes in cosmic ray flux, or climatically induced changes in the exchange rate of $CO_2$ between the ocean and the atmosphere, may likewise contribute to the oscillations occurring with time as previously proposed (*10*), but cannot account for geographical variations.

The present explanation of these oscillations may be tested by assaying series of tree-rings collected at different latitudes. The interpretation of such measurements, however, may be complicated because of the irregular, meandering course of the tropopause gap.

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## Growth Inhibition of Insects and a Fungus by Indole-3-Acetonitrile

*Abstract.* Indole-3-acetonitrile obtained from cabbage has been found to inhibit growth of *Pyrausta nubilalis* (Hbn.), *Galleria mellonella* (L.), and *Penicillium chrysogenum.*

A broad study of the resistance of the plant host to insects and fungi is being carried forth in these laboratories (*1*), and among the plants being studied is the cabbage. Several different strains of cabbage were used in the preliminary investigation.

The outer leaves of full-grown cabbage plants were removed and dried at a temperature of 60°C for 48 hours. During the drying process a loss of 90 percent in weight was observed. The dried leaves were placed in a Waring blender and reduced to a powder which was then placed in a Soxhlet extractor. Water extraction was continued for 48 hours, and the extract was filtered and concentrated in a vacuum to give a solution representing 1 g of dry plant material per milliliter of solution. The aqueous solution was extracted with ether in a continuous extractor for 24 hours. The ether extract was washed with 5 percent potassium hydroxide and with distilled water, and then it was dried with anhydrous sodium sulfate. The ether was removed in a vacuum and the residue was chromatographed on a chloroform-silicic acid column. Elution of the column with chloroform gave an oil which on purification gave an infrared spectrum having strong absorption at 4.42 $\mu$ (C≅N). Hydrolysis of the oil produced indole-3-acetic acid. The oil showed superimposable ultraviolet and infrared spectra with an authentic sample of indole-3-acetonitrile.

Table 1. Effect of indole-3-acetonitrile on growth of a fungus and two insect species.

| Indole-3-acetonitrile (mg/g medium) | Growth inhibition (%) |
|---|---|
| *Penicillium chrysogenum* | |
| 0.20 | 100.0 |
| 0.10 | 66.7 |
| 0.08* | 50.0* |
| 0.05 | 13.6 |
| 0.02 | 4.0 |
| 0.01 | 0.0 |
| *Pyrausta nubilalis* (Hbn.) | |
| 1.40 | 85.3 |
| 0.70 | 66.4 |
| 0.45* | 50.0* |
| 0.35 | 44.8 |
| 0.17 | 31.2 |
| *Galleria mellonella* (L.) | |
| 2.00 | 95.0 |
| 1.00 | 84.2 |
| 0.50 | 63.3 |
| 0.25 | 50.8 |
| 0.12 | 38.4 |
| 0.06 | 23.1 |

*Calculated from dosage-response curves.

The nitrile was found to inhibit the growth of *Pyrausta nubilalis* (Hbn.), *Galleria mellonella* (L.), and *Penicillium chrysogenum.* Previously described assay methods were employed (*2*). The inhibition at various concentrations is shown in Table 1. Indole-3-acetic acid did not inhibit growth under our assay conditions.

Previously, in a study of neutral auxins in plants, Jones and his coworkers (*3*) isolated indole-3-acetonitrile from cabbage and found it to have remarkably high activity in the oat auxin bioassay.

At present, an investigation is under way to determine if field resistance variation in cabbage plants to insects is directly proportional to the concentration of indole-3-acetonitrile. Preliminary studies have shown an average concentration of 0.016 percent indole-3-acetonitrile in cabbage on a wet-weight basis. This concentration in the plant correlates well with the amounts used to obtain growth inhibition in the laboratory. Evidence for other growth-inhibiting factors in cabbage has also been obtained.

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