When the denominator of Eq. 2 vanishes, we have a resonance. The earth's oblateness then keeps approximately constant the orientation between the perigee position and the projection of the earth-sun line onto the orbit plane. Hence, radiation pressure can increase or decrease the eccentricity monotonically. This occurs in cases C and D of Fig. 1, which were chosen so that $\dot{\mathbf{c}}$ is directed along the orbit's major axis. The average slope of each nearly straight segment of the curves for perigee height is about 10 percent less than the value given by $|\dot{\mathbf{c}}\,(\Theta = 0)|$. Actually, $\Theta$ varies over a wide range, and the detailed changes in slope correlate very well with the corresponding changes of $\cos \Theta$. The lifetime for this process is not sensitive to the model used for air density, and is sensitive to the launch time only for noncircular initial orbits.

For the Echo balloon (area-to-mass ratio 125 $cm^2/gm$) placed in a 1000-mile-altitude circular orbit, we find $|\dot{\mathbf{c}}| = 3.7$ mi/day with the sun in the orbit plane. Furthermore, if $i_0$ has the near resonance value of 35°, the lifetime is 240 days. Inclinations about the resonant value of 40° must therefore be avoided if longer lifetimes at this altitude are desired. For an initially circular equatorial orbit, the resonance altitude of 4000 miles leads to a 1.3 year lifetime, while the same orbit at 1000 mile altitude has an extremely long lifetime. The perigee height oscillations of the latter orbit have amplitudes of 60 miles and exhibit cusps at their highest points.

Smaller amplitudes of perigee height oscillation than those given by Eq. 2 result from near-equatorial initial orbits which lie close to a "stable" orbit. A stable orbit has approximately constant perigee height, and its geometric center lies on the projection of the earth-sun line at a distance $\Delta h$ from the earth's center. For other orbits the oscillation amplitude is approximately twice the distance from their initial centers to that of the stable orbit, provided that this distance is smaller than $\Delta h$. The perigee height of the equatorial stable orbit of the 1000-mile mean altitude Echo balloon lies 60 miles below this altitude.

For inclinations between 55° and 125°, even an approximate description of orbital evolution becomes considerably more complicated. Along with shorter periods, we find $2\pi/|\dot{\beta} - \dot{\Omega}_b + \dot{\omega}_b|$. When the denominator vanishes we again have a resonant condition. To understand this qualitatively, consider, for example, a satellite launched north in a resonant circular orbit, at dawn on 21 December. Since the orbit is polar, $\dot{\Omega}_b$ vanishes and $\dot{\omega}_b$ is negative. The component of radiation force in the orbit plane causes perigee to appear at the launch position. As the year progresses, this component rotates in the orbit plane in the same direction and at the same rate as the perigee position, but perigee leads by 90°. At the spring and fall equinoxes the radiation force vector lies in the orbit plane and perigee height changes at maximum rate. Perigee height thus monotonically decreases, but with a varying rate. For the same satellite launched at dusk, the radiation force component and perigee position rotate in opposite directions, resulting in a large increase in lifetime. Thus even for $e_0 = 0$ the launch time affects lifetime. The qualitative behavior of perigee for other polar orbits can be similarly analyzed. We quote one quantitative result: the Echo balloon in a resonant 2400-mile circular polar orbit has a lifetime varying from 1.3 to 3.1 years, depending on launch time (*4, 5*).

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### References and Notes

1. F. R. Moulton, *An Introduction to Celestial Mechanics* (Macmillan, New York, 1914), p. 404.
2. H. K. Kallmann, *J. Geophys. Research* **46**, 615 (1959).
3. We are indebted to Dr. Eugene Levin of the Rand Corporation for discussions about this point.
4. This work was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U.S. Army, Navy, and Air Force, and at Ramo-Wooldridge, a division of Thompson Ramo Wooldridge, Inc. under a subcontract with Lincoln Laboratory.
5. A more thorough treatment of these effects, including the effect of solar radiation reflected from the earth, is in preparation.

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## Post-Bomb Rise in Radiocarbon Activity in Denmark

*Abstract.* During the summers of 1958 and 1959 the increase in concentration of bomb-produced radiocarbon in Denmark was several percent higher than the average increase for the hemisphere. This additional increase is probably a carbon-14 equivalent to the spring peaks in strontium-90 fallout in the North Temperate Zone in the same years, and suggests latitudinal variations in carbon-14 contamination.

Measurements of bomb-produced radiocarbon have been reported by several investigators (*1–4*). Estimates of a linear yearly increase in the $C^{14}$ concentration of atmospheric carbon dioxide from the Northern Hemisphere up to 1958 have ranged from 3.2 percent [Münnich and Vogel (*2*)] to 4.3 percent [de Vries (*3*)] and 5 percent [Broecker and Walton (*4*)].

Since 1956 samples have been collected in Denmark for the purpose of monitoring the rise in $C^{14}$ in the atmosphere. The results from a series of very uniform samples are reported here.

All the samples were derived from cereals which grew in locations about 10 miles north of Copenhagen (latitude 55°50′N, longitude 12°30′E). Except for one case, only the ears of the cereals were used. These had developed and had grown during the months of June and July of the year in question. With this material, uncertainties due to unknown time lags between assimilation and deposition of carbon compounds in plant tissues of perennial plants were avoided. In June the house-heating season in Denmark has ended, and, since the area is not very heavily industrialized, there is no local Suess effect to influence the results. This is indicated by the fact that the measure for the pre-bomb decrease in $C^{14}$ in Denmark as compared to findings for 19th-century wood is 2.5 ± 0.5 percent, while the average decrease throughout the world is calculated by Fergusson to have been 2.03 ± .15 percent (*5*). The samples, therefore, should closely reflect the mean concentration of $C^{14}$ in $CO_2$ of the unchanged atmosphere at the sample locations in June and July of the growth year in question.

The sample materials are listed in Table 1, together with the measured $C^{14}$ activities. The samples were assayed as $CO_2$ in a proportional gas counter (*6*). The $C^{14}$ activities are given as

$$\Delta C^{14} = \delta C^{14} - 2\delta C^{13}\,(1 + \delta C^{14}/1000) - 50.0$$

In this expression the activity is normalized to a common $C^{13}/C^{12}$ ratio (*8*) and stated as the permillage difference from 95 percent of the activity of the National Bureau of Standards oxalic acid standard, a value which falls close to the mean activity of 19th-century wood (*4, 7*).

The rise is plotted in Fig. 1. Up to the summer of 1957 the measurements show an approximate linear rise of about 5 percent per year, which is consistent with the afore-mentioned estimates. From 1958 on, the increase is definitely steeper than reported by other investigators. From June-July 1957 to June-July 1958 the increase was 8 percent, or 3 percent more than that measured by Broecker and Walton (*4*); from the summer of 1958 to the summer of 1959 the increase was 14 percent. The 1959 value is 12 percent higher than that predicted by extrapolation of the linear curve of Broecker and Walton. Broecker and Walton's prediction was based on a curve derived from samples collected in more southern latitudes, mainly from the Great Basin in the

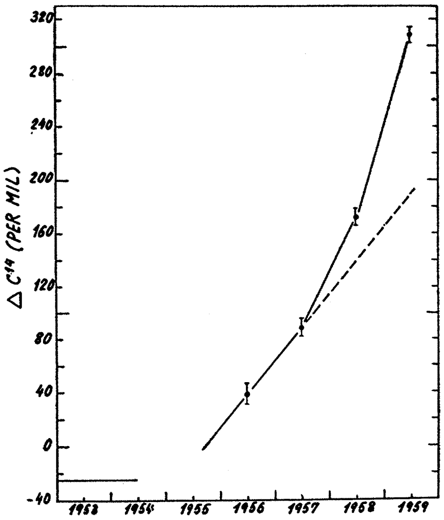


Fig. 1. Rise in $C^{14}$ activity in Danish cereals. The dotted line agrees closely with the rise found by Broecker and Walton (*4*).

United States, at about 40°N, and from North Atlantic air at 25° to 34°N. Their results undoubtedly are more representative for the Northern Hemisphere than those in this study. Although some additional increase above that predicted by them was to have been expected for 1959, it seems almost impossible that the average activity for the hemisphere could have risen to the values measured in Denmark. This would require that the total admixture of $C^{14}$ to the northern troposphere should have been more than three times as great in 1959 as in 1958. In Denmark the ratio was only 1.6.

The high values for tropospheric $C^{14}$ levels in Denmark in the summers of 1958 and 1959 most probably stem from the large increase in high-yield nuclear detonations during 1957 and 1958 in northern latitudes and in areas not far from Scandinavia. Almost all bomb-generated $C^{14}$ is injected into the stratosphere; the high $C^{14}$ values are in keeping with the findings that stratospheric debris released in northern latitudes (where the U.S.S.R. testing grounds are located) is brought down more rapidly than fallout injected into the stratosphere in the tropics (*9*). Hence, the reported levels of $C^{14}$ in Denmark, all of which are summer values, may constitute an equivalent, for $C^{14}$, to the spring peaks for $Sr^{90}$ fallout found during the same years in northern latitudes (*9, 10*).

For lack of more geographically spaced samples, it is not possible to decide whether the higher $C^{14}$ concentrations in Denmark, as compared to the measurements by Broecker and Walton, are due to latitudinal variations or to different distances from the test sites. However, particulate fallout and $CO_2$ are brought down from the stratosphere by the same circulation mechanism; the strong latitudinal dependence for fallout, which is presumably caused by a selective downward mixing from the stratosphere in middle latitudes via the gap in the tropopause (*11, 12*), therefore suggests that similar variations occur for bomb-produced $C^{14}$ in $CO_2$.

Stratospheric $CO_2$ which descends to the troposphere is not washed down with the rain, like particulate fallout, but is mixed throughout the hemisphere, with a mixing time of the order of 1 month. By this mixing, the stratospheric $CO_2$ is rapidly diluted with less active $CO_2$, and a general rise in $C^{14}$ level is produced. Only additional increase above this level is discernible as latitudinal variation. If the downward mixing from the stratosphere continues at nearly the same latitudes, and at an approximately constant rate throughout the year, a more or less permanent latitudinal gradient in $C^{14}$ concentration will be established. If the mixing from the stratosphere shows seasonal variations (*11, 13*), the gradient will grow up in the periods of descent and vanish again at other times. In the case of such seasonal variations, plant material will only exhibit latitudinal variations if the periods of descent coincide with periods of assimilation. Further, in certain areas latitudinal variations may be masked by local Suess effects, the two effects being of comparable size and of opposite direction. More measurements of the $C^{14}$ variations in tropospheric $CO_2$ from latitudinally spaced locations may provide further information on the mechanism of the stratosphere-troposphere exchange processes.

If $C^{14}$ from cosmic rays likewise comes down from the stratosphere dominantly in the North and South Temperate zones, slight latitudinal differences in natural radiocarbon activities may be present. The size of such an effect will depend on the circulation pattern in the stratosphere, which is not well understood at the moment. The effect will be more marked if the transport from stratosphere to troposphere shows definite seasonal variations, so that most $C^{14}$ comes down in the spring-time, when the rate of assimilation is highest. However, with changing climates the latitudes of dominant descent of stratospheric carbon dioxide, and consequently the zones of the highest $C^{14}$ concentrations, may have varied in the past.


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Table 1. Carbon-14 content of Danish cereals.

| Year | Sample No. (Copenhagen) | Material | $\Delta C^{14}$ |
|---|---|---|---|
| 1956 | K-612 | Barley, ears (Frederiksdal) | 39 ± 8 |
| 1957 | K-611 | Barley, ears (Sorgenfri) | 89 ± 7 |
| 1958 | K-613 | Wheat, grains (Virum) | 172 ± 7 |
| 1959 | K-610 | Rye, ears (Frederiksdal) | 308 ± 7 |
| 1959 | K-614 | Oats, straw (Naerum) | 308 ± 9 |
| 1959 | K-615 | Rye, ears (Vedbaek) | 309 ± 9 |

### References and Notes


1. T. A. Rafter and G. J. Fergusson, *New Zealand J. Sci. Technol.* **B38**, 871 (1957).

K. O. Münnich and J. C. Vogel, *Naturwissenschaften* **45**, 327 (1958).

3. H. de Vries, *Science* **128**, 250 (1958).

W. S. Broecker and A. Walton, *ibid.* **130**, 309 (1959).

5. G. J. Fergusson, *Proc. Roy. Soc. (London)* **A243**, 561 (1958).
6. The proportional counter has a sensitive volume of 2 lit., background of 5.2 count/min, assay on the National Bureau of Standards oxalic acid standard at pressure of 2 atm, 25.88 ± .091 count/min. All the samples were prepared by Elisabeth Steffensen.
7. W. S. Broecker and E. A. Olson, *Am. J. Sci., Radiocarbon Suppl.* **1**, 111 (1959).
8. The $C^{13}/C^{12}$ ratios were kindly measured by W. Dansgaard, Biophysical Laboratory, University of Copenhagen.
9. E. A. Martell, *Science* **129**, 1197 (1959).

M. Eisenbud, *ibid.* **130**, 76 (1959).

11. N. G. Stewart, R. G. D. Osmond, R. N. Crooks, E. M. Fisher, *Atomic Energy Research Establ. (G. Brit.) Publ. No. AERE HP/R 2354* (1957).
12. F. Hagemann, J. Gray, Jr., L. Machta, A. Turckevick, *Science* **130**, 542 (1959).
13. The possibility of measurable seasonal variations in the $C^{14}$ increase was pointed out in a paper by K. O. Münnich and J. C. Vogel at the $C^{14}$ symposium in Groningen, 1959.



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## Heterocaryotic Nature of Ring Formation in the Predaceous Fungus Dactylella doedycoides


*Abstract.* Morphologically indistinguishable conidia of the predaceous nematode-attacking hyphomycete *Dactylella doedycoides* Drechsler vary in their ability to produce constricting rings, depending upon their heterocaryotic state. Three types are noted: those producing rings with or without stimulation, those never producing rings, and a mixed or wild type, made up of a mixture of the first two types.


The genetic mechanisms controlling constricting ring formation in the nematode-attacking predaceous fungi are poorly understood. In the present work information concerning these mechanisms was obtained by studying ring formation in single conidial isolates derived from a monoconidial culture of *Dactylella doedycoides* Drechsler (*1*) found in garden soil in Teddington, Middlesex, England.

The initial monoconidial culture was isolated and multiplied on Difco corn meal agar at room temperature. The fungus grew readily on this medium, forming profuse numbers of erect coni-