weeks. No analyses were made for the other two species beyond the second week. Work is now under way to isolate and characterize this material. As judged visually from the chromatograms, there were quantitative differences in the composition of the protein hydrolyzates. For instance, tyrosine and phenylalanine were present only in faint traces in *Aedes aegypti* as compared with higher concentrations in *Anopheles* and *Culex*.

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The Clock Paradox

Abstract. In two-dimensional Minkowski space a geodesic arc is longer than every other admissible arc with the same end points. Thus a particle whose worldline is a geodesic—that is, an unaccelerated particle—requires more (local) time to travel between two events than an accelerated particle. Similar results in four-dimensional Minkowski space can be established.

The so-called "clock paradox" (*1*) in Special Relativity may be loosely stated by saying that if a space traveler were to take an extended trip into space, he would find upon returning to earth that he was younger than he would have been if he had remained at home. Since there is no such concept in Relativity as the same place at two different times, it is clear that a more precise formulation of the problem is required.

To simplify the problem, let us consider it in a space of one time dimension and one space dimension, and let the units be so chosen that the velocity of light is 1. In this two-dimensional Minkowski space, the element of local time is the element of arc length

$$ds = (dt^2 - dx^2)^{1/2}$$

The clock paradox is a simple problem in the calculus of variations.

Let P_1 (t_1, x_1) and P_2 (t_2, x_2) be two events, or points in Minkowski space, $t_2 > t_1$. The length of arc between P_1 and P_2 along a curve $x = f(t)$ connecting the two points is given by the line integral

$$s = \int_{t_1}^{t_2} (1 - f'^2)^{1/2} dt$$

The clock problem consists in comparing arc lengths between P_1 and P_2 along different paths.

The extremals of arc length, or geodesics, are given by the solutions of the well-known Euler equations

$$\frac{\partial \theta}{\partial f} - \frac{d}{dt}\left(\frac{\partial \theta}{\partial f'}\right) = 0$$

where $\theta = (1 - f'^2)^{\frac{1}{2}}$, and are readily found to be of the form

$$x = f(t) = at + b,$$

where $-1 < a < 1$. This is a straight line in Minkowski space and represents uniform motion in a straight line in ordinary space. Since Euler's equations are invariant under Lorentz transformations, the concept of geodesic is absolute.

Now comes the crucial difference between geodesics in Euclidean space and geodesics in Minkowski space, a difference which points up the danger of attempting to apply geometric intuition to this problem: In Minkowski space, the extremals (geodesics) represent relative maxima.

To show this, let

$$x = f(t) = at + b$$

be a geodesic connecting P_1 (t_1, x_1) and P_2 (t_2, x_2), $t_2 > t_1$, and let $\omega(t)$ be an admissible function vanishing at t_1 and t_2, so that

$$x = f(t) + \omega(t)$$

is a neighboring arc to the geodesic. The arc lengths along the geodesic and the neighboring arc are, respectively,

$$s = \int_{t_1}^{t_2} (1 - f'^2)^{1/2} dt$$

$$s + \Delta s = \int_{t_1}^{t_2} [1 - (f' + \omega')^2]^{1/2} dt$$

By the Mean Value Theorem

$$[1 - (f' + \omega')^2]^{1/2} = (1 - f'^2)^{1/2} + \frac{-f'}{(1 - f'^2)^{1/2}}\omega' + \frac{1}{2}\frac{-1}{[1 - (f' + \phi\omega')^2]^{3/2}}\omega'^2$$

where $0 < \phi < 1$. Now if $f(t) = at + b$ and $-1 < a < 1$,

$$\int_{t_1}^{t_2} \frac{-f'}{(1 - f'^2)^{1/2}}\omega' dt = \frac{-a}{(1 - a^2)^{1/2}}[\omega(t_2) - \omega(t_1)] = 0$$

so that

$$\Delta s = -\frac{1}{2}\int_{t_1}^{t_2} \frac{\omega'^2 dt}{[1 - (f' + \phi\omega')^2]^{3/2}}.$$

The integrand is never negative, and is 0 only when $\omega(t)$ is a constant and therefore 0. Thus for $t_2 > t_1$, Δs is negative for every neighboring curve. That is, the geodesic $x = at + b$ is an arc along which time is a relative maximum.

Let us assume, then, that we are in a space where there is no gravitation and that the earth is moving with constant velocity in a straight line. Then its world line in Minkowski space is a geodesic. Let P_1 (t_1, x_1) and P_2 (t_2, x_2), $t_2 > t_1$, be two distinct points on this geodesic. Any other arc connecting P_1 and P_2 would represent the time of another traveler whose motion is, for at least part of the journey, accelerated. This arc will be shorter than the geodesic so that a space traveler leaving the earth at P_1 would indeed be younger when he again met the earth at P_2 than he would have been if he had remained at home.

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Note

1. For a bibliography, see E. M. McMillan, *Science* 126, 381 (1957).

28 November 1958

Carotenogenesis and Resistance of Micrococcus pyogenes to Tetracyclines

Abstract. Although reddish-yellow pigments, mainly δ-carotene and rubixanthine, were present in the original strain of *Micrococcus pyogenes* var. *aureus*, mutants highly resistant to tetracyclines were observed to become colorless. All strains lack lipoxidase activity. The colorless strains probably reflect blocking by tetracyclines during carotenogenesis.

When *Micrococcus pyogenes* var. *aureus* (*Staphylococcus aureus*), strain 209 P, was cultured successively in media containing gradually increased amounts of tetracyclines, such as oxytetracycline, chlortetracycline, and tetracycline, acquisition of high resistance to these antibiotics was observed. In contrast to the original strain, which was sensitive to these antibiotics—that is, was killed easily by the antibiotics at a concentration of 0.5 μg/ml—and had a tinge of yellowish color, due to the presence of carotenoid pigments, the resistant strains, which withstood the addition of over 300 μg of tetracycline per milliliter of culture media, were observed to become colorless.

Both sensitive and resistant strains were grown on nutrient agar containing 2 percent glycerol and adjusted to *p*H 7.2 for mass cultivation. After incubation for 1 day at 37°C, and then for 6

days at 25°C, the cell crops were collected. The cells were first extracted with methanol and then with freshly distilled ethyl ether free of peroxides. The extracts were mixed up and concentrated under reduced pressure. The residual extract was saponified in 10 percent alcoholic potassium hydroxide solution at room temperature for 10 minutes. The solution was diluted with water and extracted with ethyl ether. The ether extracts were evaporated to dryness in a vacuum.

The residual mass thus obtained was dissolved in a small amount of petroleum ether (boiling point, 30° to 50°C) and allowed to flow onto columns which consisted of layers of calcium hydroxide and calcium carbonate. By chromatographic separation, only the original strain was ascertained spectrophotometrically to contain δ-carotene and rubixanthine (*1*). The optical densities of the extracts, at wavelengths from 370 to 530 mμ, are shown in Fig. 1.

Each strain highly resistant to tetracycline was colorless, without exception. The lack of color is not attributable to lipoxidase, for it was ascertained, by the linoleic acid method (*2*), that not only the sensitive strain but also the resistant ones were free of lipoxidase activity.

As is shown in Fig. 1, a strain highly resistant to oxytetracycline has no absorption from 370 to 530 mμ after treatment by the same method for extraction of carotenoids as was employed with the sensitive strain.

From these experimental results, it may be suggested that tetracyclines block a step or steps on the pathway of biosynthesis of carotenoids.

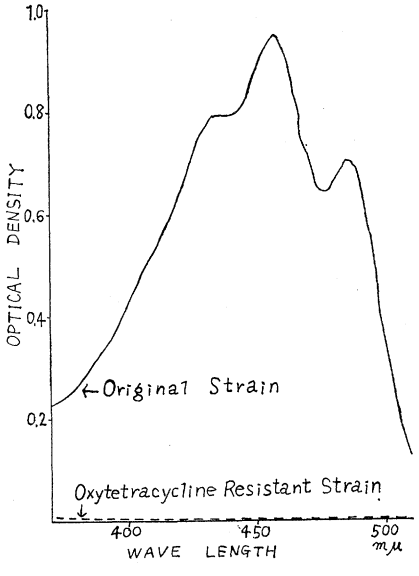

Fig. 1. Optical density versus wavelength for extracts of carotenoids from *Micrococcus pyogenes* var. *aureus* 209 P. (Solid line) Original strain; (dashed line) oxytetracycline (300 μg/ml) resistant strain. Solvent, *n*-hexane; concentration of extract, that obtained from 20 mg (dry weight) of cells per milliliter of *n*-hexane; instrument used, Beckman spectrophotometer model DU.

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Half-Life of Sulfur-35

Abstract. A new determination has been made of the half-life of the beta emitter sulfur-35. Approximately 400 measurements were taken over a period of a year and a half. These data were corrected for the dead time of the counter and then treated statistically. The half-life was found to be 86.35 ± 0.17 days.

One of the most commonly used radioisotopes in chemical and biological tracer experiments is S^{35}. For accurate work, it is necessary to make a correction for the decay of the isotope; this requires a precise knowledge of the decay rate. The uncertainty associated with the presently accepted half-life of S^{35} limits the accuracy of certain types of experiments. Accordingly, we undertook to determine a more precise value for the half-life.

The decay rate λ is defined by the equation

$$\ln N - \ln N_0 = -\lambda t \qquad (1)$$

where N_0 is the initial count rate and N is the count rate at time t. It is clear from this equation that if only one radioisotope is present, ln N will be a linear function of time. Thus, radioactive contamination of a radioisotope can be detected by a nonlinearity in this relationship. A secondary objective of our experiment was to determine whether such contamination was present.

The S^{35} sample was in the form of $CaS^{35}O_4$ deposited on a copper planchet. A thin layer of clear Krylon was placed over the source to prevent the loss of radioactive material.

The planchet containing the source was placed in one of the wells of a shielded, gas flow counter. A C^{14} source consisting of a thin plastic film mounted in a planchet was placed in the second well, and the third well was used for background measurements. The C^{14} was used as a constant source to check the efficiency of the counter and insure that it did not change over the period of the experiment. These sources were not touched during the entire experiment, so that each geometry remained the same. The well counter protected the sources from dust which might have absorbed part of the beta radiation, and a visual inspection before and after the experiment indicated that the appearance of the sources had not changed.

Counts were taken at a standard time each day for periods of 10 minutes each on the three wells of the flow counter. Four hundred and one sets of measurements were made over a period of 500 days. During this time the mean background rate was 24 count/min (range, 21 to 27 count/min), and the C^{14} readings were constant within 1 percent. The initial counting rate of the S^{35} was approximately 1300 times the background rate; by the end of the experiment about 1½ years later, the counting rate had decreased to about 30 times background.

Because the counting rate was fairly high, a correction had to be made for the counts lost during the dead time of the counter. A measurement of the resolution was made by the standard method of splitting a planchet into two pieces and placing a drop containing the S^{35} compound on each. The counting rate was then measured for each drop separately and for the two together. The dead time is given by

$$\tau = \frac{2(n_1 + n_2 - n_3)}{(n_1 + n_2)n_3} \qquad (2)$$

where n_1 and n_2 are the counts due to the separate drops and n_3 is the count when both drops are measured together. The dead time found for the flow counter used in this experiment was 149.1 μsec, which agrees well with the manufacturer's specifications.

Because the variation in the C^{14} counts was small, no correction was made for detector efficiency. The background count measured each day was subtracted from the S^{35} count, and the difference was taken as the measured count for that day. In order to obtain the actual count, a correction was made for the counts lost because of the finite dead time of the counter. The measured count can be written as

$$n = N - nN\tau$$

where N is the actual count and τ is the dead time of the counter (Eq. 2). Since n and τ were known, a value for the actual count, N, was found for each measurement.

$$N = n/(1 - n\tau) \qquad (3)$$

During the early part of the experiment when the counting rate was high, the