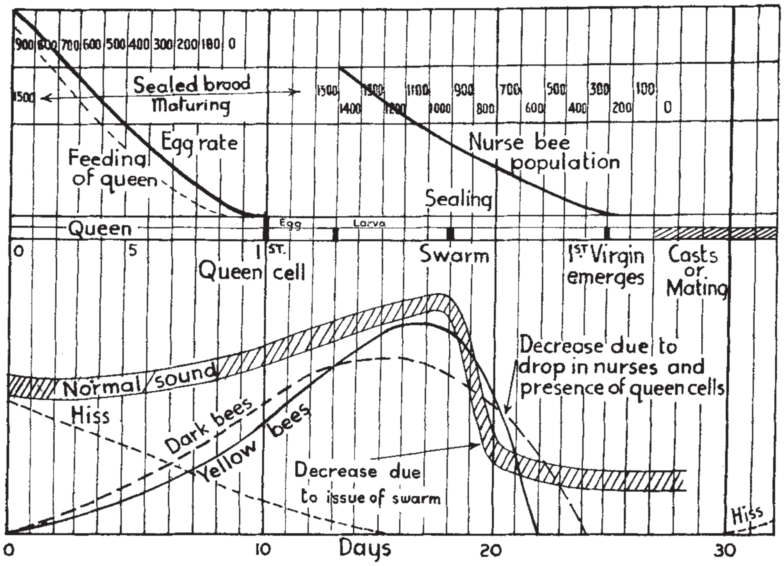

Fig. 3. Swarm cycle

warble. Furthermore, the warble 'radiates' from the queen, which is usually at the top of the brood-box, away from the entrance.

Disturbance was eliminated, and the relative volume of the warble increased by placing a microphone permanently inside the hive at the top, but the adverse conditions of heat and humidity destroyed the (crystal) microphone fairly quickly, and the running cost of one microphone per hive per season was excessive.

A scheme which has proved successful and economical utilizes a hole in the back of the brood-box at the top, with an internal screen of perforated zinc, and plugged with a rubber bung. This bung is removed and the microphone, mounted in an identical bung, plugged in. This third plan also removes a disadvantage of the second, namely, the variability of microphones, especially after some weeks in the hive.

Headphones, of the familiar stethophone pattern, are used as a detector, but later development may permit the use of a visual indicator, at an increased cost. An automatic alarm system is also possible for use in large centralized apiaries.

The 'Apidictor' was primarily visualized as a swarm predictor, for which it has obvious economic advantages, but it has a great range of other uses. It removes almost completely the uncertainty of queen introduction and queen cell acceptance, it detects abnormalities such as queen failure, that is, drone breeding, and it enables an accurate check to be made of the health of the colony in winter, even during heavy frost.

I wish to acknowledge the enthusiastic and skilled co-operation of many friends, but particularly of Mr. E. F. Birch of Hereford, who has been working with me since 1951, and of Mr. C. B. Dennis of Harrow, who has co-operated with me for the past three years. I also wish to thank Messrs. Wayne Kerr Laboratories of Surrey, for invaluable technical assistance.

[1] British Patent No. 729,067 (1958).

SEARCHING FOR INTERSTELLAR COMMUNICATIONS

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NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation ; (2) origin of life ; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known ; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We shall assume that long ago they established a channel of communication that would one day become known to us, and that they look forward patiently to the answering signals from the Sun which would make known to them that a new society has entered the community of intelligence. What sort of a channel would it be ?

The Optimum Channel

Interstellar communication across the galactic plasma without dispersion in direction and flight-time is practical, so far as we know, only with electromagnetic waves.

Since the object of those who operate the source is to find a newly evolved society, we may presume that the channel used will be one that places a minimum burden of frequency and angular discrimi-

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nation on the detector. Moreover, the channel must not be highly attenuated in space or in the Earth's atmosphere. Radio frequencies below ~1 Mc./s., and all frequencies higher than molecular absorption lines near 30,000 Mc./s., up to cosmic-ray gamma energies, are suspect of absorption in planetary atmospheres. The band-widths which seem physically possible in the near-visible or gamma-ray domains demand either very great power at the source or very complicated techniques. The wide radio-band from, say, 1 Mc. to 10^4 Mc./s., remains as the rational choice.

In the radio region, the source must compete with two backgrounds : (1) the emission of its own local star (we assume that the detector's angular resolution is unable to separate source from star since the source is likely to lie within a second of arc of its nearby star) ; (2) the galactic emission along the line of sight.

Let us examine the frequency dependence of these backgrounds. A star similar to the quiet Sun would emit a power which produces at a distance R (in metres) a flux of :

$$10^{-15}f^2/R^2 \quad \text{W.m.}^{-2}(\text{c./s.})^{-1}$$

If this flux is detected by a mirror of diameter l_d, the received power is the above flux multiplied by l_d^2.

The more or less isotropic part of the galactic background yields a received power equal to :

$$\left(\frac{10^{-12\cdot 5}}{f}\right)\left(\frac{\lambda}{l_d}\right)^2 (l_d)^2 \quad \text{W.(c./s.)}^{-1}$$

where the first factor arises from the spectrum of the galactic continuum, the second from the angular resolution, and the third from the area of the detector. Thus a minimum in spurious background is defined by equating these two terms. The minimum lies at :

$$f_{\text{min.}} \approx 10^4 \left(\frac{R}{l_d}\right)^{0\cdot 4} \text{ c./s.}$$

With $R = 10$ light years $= 10^{17}$ m. and $l_d = 10^2$ m., $f_{\text{min.}} \approx 10^{10}$ c./s.

The source is likely to emit in the region of this broad minimum.

At what frequency shall we look ? A long spectrum search for a weak signal of unknown frequency is difficult. But, just in the most favoured radio region there lies a unique, objective standard of frequency, which must be known to every observer in the universe : the outstanding radio emission line at 1,420 Mc./s. (λ = 21 cm.) of neutral hydrogen. It is reasonable to expect that sensitive receivers for this frequency will be made at an early stage of the development of radio-astronomy. That would be the expectation of the operators of the assumed source, and the present state of terrestrial instruments indeed justifies the expectation. Therefore we think it most promising to search in the neighbourhood of 1,420 Mc./s.

Power Demands of the Source

The galactic background around the 21-cm. line amounts to :

$$\frac{dW_b}{dS\ d\Omega\ df} \approx 10^{-21\cdot 5} \quad \text{W.m.}^{-2}\ \text{ster.}^{-1}\ (\text{c./s.})^{-1}$$

for about two-thirds of the directions in the sky. In the directions near the plane of the galaxy there is a background up to forty times higher. It is thus economical to examine first those nearby stars which are in directions far from the galactic plane.

If at the source a mirror is used l_s metres in diameter, then the power required for it to generate in our detector a signal as large as the galactic background is :

$$\frac{dW_s}{df} = \frac{dW_b}{dS\ d\Omega\ df}\left(\frac{\lambda}{l_s}\right)^2\left(\frac{\lambda}{l_d}\right)R^2 = 10^{-24\cdot 2}\ R^2/l_s^2 l_d^2 \quad \text{W.(c./s.)}^{-1}$$

For source and receiver with mirrors like those at Jodrell Bank (l = 80 m.), and for a distance $R \simeq 10$ light years, the power at the source required is $10^{2\cdot 2}$ W.(c./s.)$^{-1}$, which would tax our present technical possibilities. However, if the size of the two mirrors is that of the telescope already planned by the U.S. Naval Research Laboratory (l = 200 m.), the power needed is a factor of 40 lower, which would fall within even our limited capabilities.

We have assumed that the source is beaming towards all the sun-like stars in its galactic neighbourhood. The support of, say, 100 different beams of the kind we have described does not seem an impossible burden on a society more advanced than our own. (Upon detecting one signal, even we would quickly establish many search beams.) We can then hope to see a beam toward us from any suitable star within some tens of light years.

Signal Location and Band-Width

In all directions outside the plane of the galaxy the 21-cm. emission line does not emerge from the general background. For stars in directions far from the galactic plane search should then be made around that wave-length. However, the unknown Doppler shifts which arise from the motion of unseen planets suggest that the observed emission might be shifted up or down from the natural co-moving atomic frequency by ± ~300 kc./s. (± 100 km. s.$^{-1}$). Closer to the galactic plane, where the 21-cm. line is strong, the source frequency would presumably move off to the wing of the natural line background as observed from the direction of the Sun.

So far as the duration of the scanning is concerned, the receiver band-width appears to be unimportant. The usual radiometer relation for fluctuations in the background applies here, that is :

$$\frac{\Delta B}{B} \propto \sqrt{\frac{1}{\Delta f_d \cdot \tau}}$$

where Δf_d is the band-width of the detector and τ the time constant of the post-detection recording equipment. On the other hand, the background accepted by the receiver is :

$$B = \frac{dW_b}{df}\ \Delta f_d \text{ and } \tau \propto \frac{\Delta f_d}{(\Delta B)^2}$$

If we set ΔB equal to some fixed value, then the search time T required to examine the band F within which we postulated the signal to lie is given by :

$$T = \frac{F\tau}{\Delta f_d} \propto \frac{F}{(\Delta B)^2}$$

independent of receiver band-width Δf_d.

Of course, the smaller the band-width chosen, the weaker the signal which can be detected, provided $\Delta f_d \geqslant \Delta f_s$. It looks reasonable for a first effort to choose a band-width Δf_d normal in 21 cm. practice, but an integration time τ longer than usual. A few settings should cover the frequency range F using an integration time of minutes or hours.

Nature of the Signal and Possible Sources

No guesswork here is as good as finding the signal. We expect that the signal will be pulse-modulated with a speed not very fast or very slow compared to a second, on grounds of band-width and of rotations. A message is likely to continue for a time measured in years, since no answer can return in any event for some ten years. It will then repeat, from the beginning. Possibly it will contain different types of signals alternating throughout the years. For indisputable identification as an artificial signal, one signal might contain, for example, a sequence of small prime numbers of pulses, or simple arithmetical sums.

The first effort should be devoted to examining the closest likely stars. Among the stars within 15 light years, seven have luminosity and lifetime similar to those of our Sun. Four of these lie in the directions of low background. They are τ Ceti, 0_2 Eridani, ε Eridani, and ε Indi. All these happen to have southern declinations. Three others, α Centauri, 70 Ophiucus and 61 Cygni, lie near the galactic plane and therefore stand against higher backgrounds. There are about a hundred stars of the appropriate luminosity among the stars of known spectral type within some fifty light years. All main-sequence dwarfs between perhaps $G0$ and $K2$ with visual magnitudes less than about $+6$ are candidates.

The reader may seek to consign these speculations wholly to the domain of science-fiction. We submit, rather, that the foregoing line of argument demonstrates that the presence of interstellar signals is entirely consistent with all we now know, and that if signals are present the means of detecting them is now at hand. Few will deny the profound importance, practical and philosophical, which the detection of interstellar communications would have. We therefore feel that a discriminating search for signals deserves a considerable effort. The probability of success is difficult to estimate ; but if we never search, the chance of success is zero.

METABOLIC CHANGES INDUCED IN MAMMALIAN ERYTHROCYTES BY WHOLE-BODY X-IRRADIATION

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APPLICATION of X-rays and radium in medicine, after their discovery during 1895–96, established their effectiveness in diagnosis and treatment of disease. Only somewhat later were the lethal and injurious properties of these penetrating rays recognized[1]. Since then, large groups of men have become exposed more frequently to man-made radiation. These additional exposures to penetrating radiation have magnified the need for a reliable indicator of radiation-induced tissue damage. What is precisely needed is a simple and accurate indicator which would correlate biological damage with the radiation dose[1].

The requirements of an ideal biological radiation indicator are that : (*a*) a tissue or tissue component should show changes over extended periods following whole-body irradiation ; (*b*) this change can be quantitatively measured. It is also important that tissue samples should be available for intermittent sampling without injury to the subject and without alteration in the system under examination.

Choice of Erythrocytes

Certain generalizations can be used in considering this problem in order to initiate a working hypothesis. Tentatively it can be assumed that any radiation absorbed by cells will cause changes in the cell enzymes[2], but that the detection of these changes is dependent on (*a*) the sensitivity to radiation of a particular enzyme system under evaluation and (*b*) the degree of sensitivity of the analytical methods employed.

Implicit in the above specifications is the fact that the tissue must be incapable of extensive internal repair if it is to reflect any post-irradiation changes. This immediately eliminates tissues with large populations of mitotic cells and suggests erythrocytes as the tissue component of choice. In man the erythrocyte has a life-span of 110–120 days[3], in the rat this span is 49–55 days[4], in other mammals erythrocyte life-spans are between these values[5]. Since mammalian erythrocytes are enucleated, no resyntheses of proteins can occur, and any radiation damage incurred on the enzyme-proteins, such as denaturation or rupture of peptide linkage, should be detectable by changes in enzymic reactions. This rationale suggests the erythrocyte enzymes for examination as a test system.

If the hypothesis is held that any absorbed radiation will affect enzymes in all cells, how is it that no enzymic changes have been observed in erythrocytes after moderate whole-body irradiation ? This may be explained on the basis that up to the present time few erythrocyte enzymes have been tested after radiation treatment. Erythrocyte enzymology has now been more thoroughly explored[6,7]. With the complete elucidation of glycolysis, the hexosemonophosphate shunt, the transketolase and transaldolase enzymes, and nucleoside phosphorylase in erythrocyte extracts, re-examination of the radiation effect on these enzyme systems is in order.

Nucleoside Metabolism

Investigators concerned with the preservation of blood have found that when inosine or adenosine is added to blood the integrity of the erythrocytes is maintained during storage and their survival following transfusion is improved[8]. This was attributed to the resynthesis of metabolites essential for erythrocyte integrity.