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IS INTERSTELLAR TRAVEL POSSIBLE ?

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In a brilliant essay, it is shown by Edward Purcell (" Interstellar Communication ", A. G. W. Cameron Ed., Benjamin, New York, 1963; pp. 121-143) that direct communication by travel and return between stellar systems of the Galaxy is virtually impossible, if time intervals of less than a human life span are desired. The conclusion rests on general physical principles, and not on the degree of technical progress of a population of intelligent beings. With relativistic dilatation of time, at speeds approaching *c*, the velocity of light, the crew of a spaceship could make the trip, returning to earth centuries later but feeling older by a few years only. However, to reach the required speed, even with the absolutely most powerful rocket fuel (at present existing only in our imagination), antimatter, the return trip would require the expenditure of 40,000 tons of the fuel, for each ton of the payload. The fuel, ton for ton of antimatter and matter, explodes on contact, with a power of 1000 times that of a hydrogen bomb of equal mass. Its production and storage " is clearly a very serious problem " modestly admits Carl Sagan (*Planet. Space Sci.*, pp. 485-498, 1963), a proponent of interstellar travel. [" Conventional nuclear fuel " of the hydrogen variety (not yet working, except in the bomb) would require, theoretically, a fuel payload ratio of 40000 to the power 8 or 10^{37}.] The exhaust power of the antimatter rocket would equal the solar energy power received by the earth—all in gamma rays. " So the problem is not to shield the *payload*, the problem is to shield the *earth* " (Purcell). Besides, of antimatter, only a few antiprotons have been observed or made in the laboratory so far.

Thus, " conventional " rockets are no good for interstellar travel. A remedy, nevertheless, is proposed by R. W. Bussard (*Astronautica Acta*, 6, p. 179, 1960) and accepted by Sagan. It is the ramjet working by intake of interstellar gas and ejecting it with the " conventional " energy gain, derived from nuclear fusion of the interstellar hydrogen (deuterium chain ending in helium). For 1 to 1000 hydrogen atoms per cm^3 of interstellar space, the machine would require 10^4 — 10^7 km^2 of intake area for a payload of 1000 tons or 10^5 — 10^8 cm^2 per gr of payload—a veritable cobweb structure. Let us take a closer look at the physical soundness of the proposal.

It can be rejected outright because, at collision energies in the Bev range, nuclear fusion cannot take place except at a negligible rate. As soon as a compound nucleus is formed, it is broken up in the next collision. Neutrons are formed, and energy is absorbed instead of being produced. Nevertheless, let us condone this oversight by the proponents of the ramjet, and inquire into what happens if it is assumed that, by some miracle, nucleons combine at every collision and are never broken up.

The problem of energy losses comes first. The gas flowing in with the velocity of the vehicle (nearly c) must be captured, or contacted in some way, and then ejected backwards with increased energy and momentum. Let $\beta = (1 - v^2/c^2)^{-\frac{1}{2}}$ be the relativistic factor, so that for a vehicle travelling with velocity v relative to the gas, the mass of the gas particles appears to be increased β times, whereas time intervals as measured inside the vehicle are decreased β times as compared with those in the gas assumed to be practically "at rest" with the slow-moving stars and planetary systems. Thus, when $v = 0.98c$, $\beta = 5$; each impinging proton of the interstellar gas will have a fivefold mass, $1.66 \times 10^{-24} \times 5 = 8.3 \times 10^{-24}$ gr, as viewed from the vehicle; a distance of 98 light years will be covered by the vehicle in 100 years as viewed from earth, but only in 20 years as measured in biological time of the crew. Let a fraction q of the kinetic energy of the gas be lost on contact or containment, and let α be the mass defect measuring the energy αc^2 per gr, obtainable in nuclear fusion, with ϵ as the coefficient of efficiency of the fusion reaction. The net thrust, or forward propelling momentum (Γ) per gr of gas is then (for $v \sim c$), to first order terms of α and $1/\beta$, and when q is small (necessary condition for the machine to work),

$$\Gamma = [\alpha\epsilon - q\,(\beta - 1)]\,c. \qquad (1)$$

For positive thrust, the following condition must be fulfilled:

$$q < \alpha\epsilon/(\beta - 1). \qquad (2)$$

With $\alpha = 0.007$ as for hydrogen burning to helium, $\epsilon = 0.6$ as depending on γ and neutrino loss, $\beta = 5 - 1000$ as in Sagan's essay, the condition $q < 10^{-3} - 10^{-5}$ obtains. If more than 0.1 to 0.001 per cent of the kinetic energy is radiated away at encounter, the "ramjet" will reduce, not increase the momentum of the vehicle.

The mean free path of protons in interstellar gas at these energies exceeds the dimensions of the Galaxy. Therefore, no true ramjet can be devised; no semiadiabatic compression of the inflowing gas can take place, before it is additionally heated and ejected with higher energy (yet if it could be adiabatically compressed, annihilating temperatures of 10^{12} deg K would obtain). The gas atoms move as cosmic rays (of many Bev) without collisions between themselves. If solid containing surfaces are used, $q \sim 1$ and all the energy will be lost. For this reason alone (there are many others), only magnetic containment of a plasma can be considered at all; cyclotron and synchrotron radiation, as well as collisions with the solid framework will lead to detrimental losses in this case, too, as shown later on; but let us first assume that sufficiently low values of q can be achieved somehow. In such a case, following Sagan, there must be an interstellar plasma available, and of a desirable density of some 1000 per cm^3. In the solar neighbourhood, the density is only 1 per cm^3, and the hydrogen is neutral, so here the ramjet would not work without somehow ionizing the gas. These most favourable conditions would thus correspond to the interior, say, of the Orion Nebula. If we cannot get there, the inhabitants of solar systems imbedded in the nebula perhaps could make use of its ionized dense gas to pay visits to each other. Never mind the heating of the framework (spiderweb wires over hundreds of kilometres) which would lead to a radiative equilibrium temperature of 5000° K (superconductivity and thus near-zero temperatures are however suggested for magnetic containment). Assume also $q = 0$ and $\epsilon = 1$, thus absolutely no losses. Equation (1) in such a case yields a thrust of

$$\Gamma = \alpha c = 2.1 \times 10^8 \text{ cm/sec}$$

per gr of " processed " plasma. The required acceleration is $1\ g = 1000 \text{ cm/sec}^2$ at least (to get the effect in a few years' time), which means that

$$g/\Gamma = 5 \times 10^{-6}$$

gr of the plasma must be funnelled through the ramjet per second for each gr of the payload. The density of the plasma is 2×10^{-21} gr/cm^3, its velocity $v \sim c = 3 \times 10^{10}$ cm/sec, which gives a flow of 6×10^{-11} gr per cm^2 of cross-section and second. The intake area must thus be $5 \times 10^{-6}/6 \times 10^{-11} = 8 \times 10^4 \text{ cm}^2$ per gram. With a payload of 1000 tons as envisaged, the intake area becomes 8000 square kilometres, corresponding to a radius of the intake nozzle equal to 50 kilometres.

The inflowing plasma must be contained and funnelled by magnetic fields. A central magnetic dipole, located within the payload, can never reach the required intensity without destroying itself. Solenoid fields covering the entire intake area would be needed, produced by a cobweb of electrical wires over the entire intake and ejection volume. The propelling force must, evidently, also be transmitted through the seat of the magnetic field—the wiring. It must thus possess a certain strength, and have therefore a minimum weight which can be estimated as follows. The most economic way would be to rely on tensile stresses only (which, however, is not possible). Assume that the acceleration is transmitted to the payload by wires of an extraordinary tensile strength of 5 tons per cm^2 (steel would not be safe with such a load), pulling in a forward direction. The weight of the payload at 1 g is 1000 tons and the cross-section of the transmitting wires must thus be 200 cm^2. With a length of 100 km at least or twice the radius of the intake cross-section, this makes out $2 \times 10^9 \text{ cm}^3$ or 16,000 tons of steel wires—for a payload of 1000 tons. The wires are unable to cope with their own weight. Transversal connections, cross-beams, etc., would greatly add to this figure. Evidently, the machine cannot be made rigid enough for work without collapsing.

With a cross-section for nuclear collisions of 10^{-25} cm^2, at a density of 10^3 nucleons per cm^3 it would take a path length of 10^{22} cm, or a time interval of 10,000 years for a proton to meet another (without necessarily combining).

To obtain a sufficient reaction rate, the collision time must be of the order of the time t of the containment of the plasma; with the dimensions as assumed before, $t = 10^4$ sec and a number density for the trapped protons of $N = 3 \times 10^{10}$ per cm^3 is required. The protons will have to accumulate into a radiation belt of so high a density (10^{16} times that of the Van Allen belt) that all the wiring will be annihilated by heat, long before this density is reached.

With such a high density of the radiation belt, the gas pressure is 240 atmospheres, and the containing magnetic field must not be less than 2.5×10^5 Gauss (and not a few hundred as mentioned by Sagan). Pressures and stresses far in excess of those due to net acceleration will arise, blowing this cobweb of electric wiring to smithereens. On the other hand, with such a field, synchrotron radiation will consume the kinetic energy of the electrons in 0.01 sec [*cf.* G. R. Burbridge, *Astroph. J.*, 128, p. 1, 1958, equ. (2)], 600 times faster than the nuclear collision rate (which is not yet the reaction rate). Four times this amount will be restored in collisions with protons and radiated away during the time needed for one proton to collide elastically with another. Hence, from synchrotron radiation alone, $q = 0.003$, which already exceeds the permissible upper limit. In addition, it can be shown that with the most slender solid framework, collisions with the material of the wiring will dissipate the energy of the gas hundreds of times faster than is the rate of collisions between the protons of the belt.. This makes $q \sim 1$ instead of the required low values of equ. (2), and the machine cannot work, even in the case of the assumed miraculous efficiency of the nuclear reactions. The difficulty is similar to that in contemporary experiments with non-explosive thermonuclear fusion.

One could go on with other similar arguments. Those already put forward are amply sufficient to prove that the " ramjet " mechanism is impossible everywhere, as well as inside the Orion Nebula — and one must get there first. " Travelling around the universe in space suits—except for *local* exploration . . . . belongs back where it came from, on the cereal box " (E. Purcell, *loc. cit.*). It is for space fiction, for paper projects—and for ghosts. " The only means of communication between different civilizations thus seems to be electro-magnetic signals " (S. von Hoerner, " The General Limits of Space Travel ", in " Interstellar Communication ", pp. 144-159). These conclusions, of course, refer to locomotion at near the speed of light. Slower motion (up to 0.01 c) is a problem of longevity or hereditary succession of the crew; this we cannot reject because we do not know anything about it.

Armagh Observatory,

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