LETTERS TO NATURE

PHYSICAL SCIENCES

Black Holes and Temporal Ordering

THE "Arrow of Time" has been much discussed by philosophers and by some scientists[1], and various manifestations, which have also been offered as explanations of this directionality, are to be noted in the world around us. For example, asymmetry of time is observed in thermodynamics, an increase in entropy is predicted from statistical mechanics, there is a consistent choice of retarded solutions to time symmetric equations of radiation theory and expansion of the universe is deduced from cosmological theory; in addition a temporal arrow is inferred from the asymmetry of matter and antimatter in the universe. A striking feature of such observations is that the directions of the arrows agree.

Within general relativity it is necessary to impose time orientability on the E_4 manifold such that the arrows placed on timelike world lines agree in sign. Thus an assumption is made concerning temporal asymmetry which may not be derivable within the context of general relativity.

A theory purporting to explain "Time's arrow"[2] generally involves a plausibility argument concerning one of these arrows within a system which is in contact with its complement, the remainder of the universe. The universe is supposed to act as an infinite sink for the dissipation of energy from the system, and, as a result of the interaction or interdependence of all systems and processes, it is concluded that all of the manifestations of temporal asymmetry within the universe agree on direction.

A consequence of this argument is that within a system isolated from the remainder of the universe, asymmetry of temporal order may not be maintained; in other words, the system will reach a state of dynamical equilibrium. To some extent a Black Hole provides such a situation, since world lines and radiation may not escape from a system which has fallen through its Schwartzschild radius[3]. It is, however, possible for exterior particles and radiation to enter the hole, and some of its rotational energy may be extracted from the ergosphere[3].

The Wheeler–Feynman absorber theory of radiation[4] offers an explanation for the appearance of retarded radiation, resulting from initially time symmetric solutions to Maxwells equations, by establishing a connexion with the thermodynamic properties of matter in the universe. Within a Black Hole, however, while retarded signals converge towards the origin of the singularity, it is possible for advanced signals to escape along past pointing null cones. Within the Wheeler–Feynman explanation one would be faced with the possibility of the reversal of temporal direction inside the hole and the emission of advanced radiation.

Thermodynamic arguments within a Black Hole require an unambiguous meaning to be given to the notion of entropy within the hole. It would appear, however, that dissipative processes with the attendant spontaneous increase in "disorder" are not possible within the Hole.

It therefore seems reasonable to question the assumption of a fixed temporal direction for the collapse of a Black Hole and the issue of the final state. Indeed, one may go further and question the meaning of the terms "time" or "proper time" as applied to processes within the Black Hole since, as a result of the bending of light cones towards the origin, it is not generally possible to construct a "clock" in which retarded signals are exchanged between two world lines inside the hole. Thus the nature of temporal flow in regions of pathological geometry is ambiguous.

My object here is to draw attention to one of those classical assumptions as to the nature of time which has remained unexamined in the light of quantum physics and general relativity, and to stimulate discussion directed towards clarification of these matters.

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1 Whitrow, G. J., *The Natural Philosophy of Time* (Nelson, London, 1961).
2 *The Nature of Time* (edit. by Gold, T., and Schumacher, D.) (Cornell University Press, New York, 1967).
3 Penrose, R., *Riv. nuovo Cim.* (*Numero speciale*), **252** (1963).
4 Wheeler, A. J., and Feynman, R. P., *Rev. Mod. Phys.*, **21**, 425 (1949).

Is the African Plate Stationary?

THE islands of St Helena, Tristan da Cunha and Gough lie respectively 500 km, 450 km and 450 km east of the crest of the Mid-Atlantic Ridge[1] (Fig. 1). We believe that they overlie hot spots or convective plumes in the mantle and that the Walvis Ridge is the trail of a hot spot marking the relative motion of the African plate over the mantle since the opening of the South Atlantic[2,3]. We suggest that the termination of the ridge at Tristan and Gough records the cessation of this relative motion. That this occurred about 25 m.y. ago is indicated by a spreading rate of 1.7 cm/yr/side and because the two islands lie just east of magnetic anomaly six[4]. Spreading of the sea floor continued and has moved the crest west from the hot spots. The Discovery and Meteor seamount chains are concentric with the Walvis Ridge; they too terminate some distance east of the crest of the Mid-Atlantic Ridge and may also be hot spot trails terminating on the same isochron. The position of Bouvet Island is harder to interpret because of its location at the western end of the Atlantic-Indian Ridge.

On the other side of the African plate, Mauritius and Reunion (200 km apart) also lie on anomaly six at the end of a ridge concentric with the Walvis Ridge[5] which suggests that they also overlie a plume. At the same time that relative motion between the African plate and mantle ceased (25 m.y. ago) the pattern of spreading in the Indian Ocean altered and what had been the Chagos Fracture Zone became the crest of a new Central Indian Ridge[5]. Its subsequent spreading has created young ocean floor east of Mauritius.

Stratigraphic evidence and K/Ar dates from widely separated areas on the African plate indicate a roughly simultaneous upsurge in volcanic activity about 25 m.y. ago (Table 1). If this volcanism was generated over plumes and the African plate has moved laterally over them during the past 25 m.y., then the volcanoes should form parallel lines across Africa.