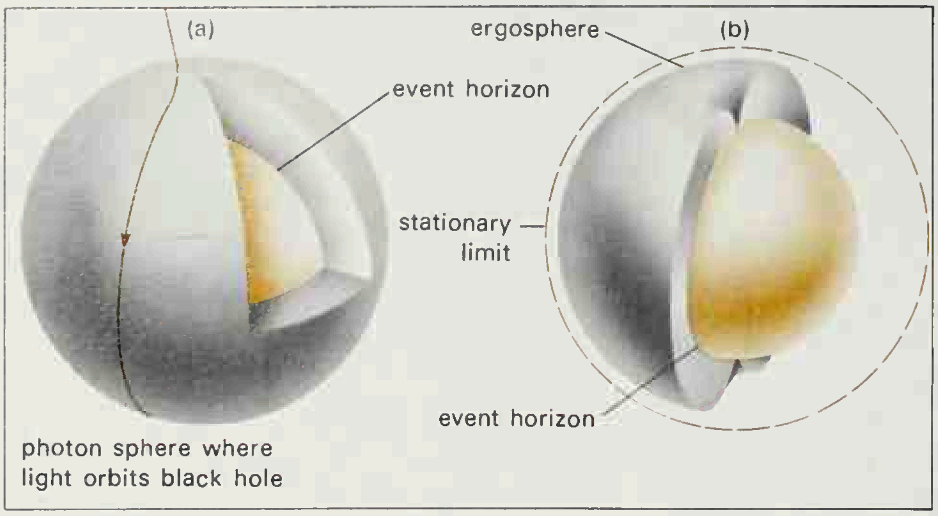


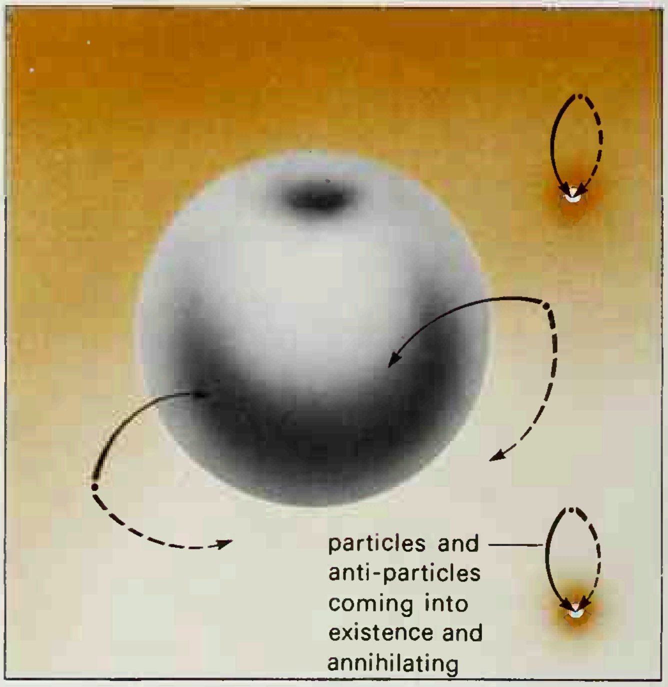


Fig. 8·8 above: These drawings depict the limits of a non-rotating black hole (a), and a rotating black hole (b) as calculated by Roy Kerr. In the latter anything such as photons and particles lying below the 'stationary limit' must keep in motion on the 'ergosphere' or 'work space' otherwise they will fall into the black hole. In theory a beam of light or even an astronaut could escape from the ergosphere.

Fig. 8·9 top right: Stephen Hawkings' idea that in the neighbourhood of a black hole some nuclear particles may escape.

Fig. 8·10 far right: The age of the universe can be calculated: supposing we have a certain value for the Hubble constant, we obtain a beginning at 0, but this is only valid if gravity did not have a greater effect when the galaxies were close together. Since gravity will have such an effect, the 'origin' will lie elsewhere. B is just such a point; its position will depend on the model universe we choose.

Cosmological models

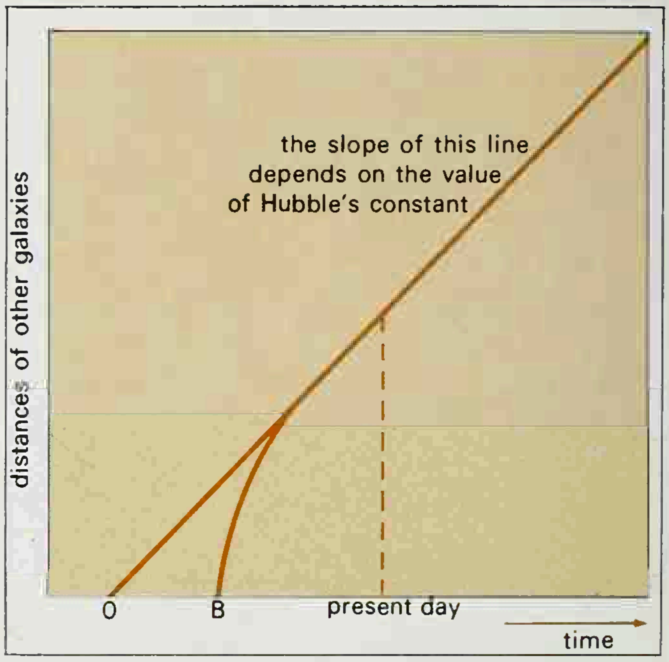
The cosmologist, applying the theory of relativity, can make various theoretical 'models' of the universe: these can then be compared with the results from observation, hopefully, to determine which model is the correct one. As we shall see, however, it is not possible to come down firmly in favour of one model only, although some models can be eliminated, and a general idea about the nature of the universe can be reached.

Relativistic models of the universe are based on what is sometimes called the **cosmological principle**, which states that on the largest scale the appearance of the universe at any given time is the same for all observers located in, and moving with, galaxies; and, for simplicity's sake, all matter in the universe is 'smoothed out', that is, it is assumed that the universe is one vast uniform 'fluid'.

In 1917, in his first relativistic model of the universe, Einstein assumed the universe was static and, to prevent it collapsing under the influence of gravity, he introduced a cosmological term which showed a repulsion. Once the expansion of the universe had been discovered, new models were devised in the 1920s and 1930s by Einstein and Willem de Sitter, by Edward Milne, the Abbé Lemaître, and the Russian, Alexander Friedmann. All were what we should today call big-bang universes in that they all considered the universe to have started in a concentrated form (Fig. 9·10).

The Milne model, sometimes known as the kinematic relativity model, uses Euclidean space and special relativity as far as possible. It takes the total mass in the universe to be small and the movement of the galaxies as uniform; thus the 'age of the universe' could be determined quite simply from galaxian distances and velocities. On this model, devised in the 1930s, the age of the universe came out at 2×10^9 years, although using more modern figures this would work out as $1{\cdot}5 \times 10^{10}$ years. The theory involved the use of two time scales, one basic in the universe, the other local to a moving observer. This gave rise to a kinematical redshift, greater for more distant galaxies, but very much smaller than the total redshift observed in any particular galaxy.

The Friedmann models were straightforward, giving an expansion which, after a time, continued at an ever decreasing rate. However, the age of the



universe they produced seemed too short considering the evidence there was then for the age of the Earth. The Einstein-de Sitter model, which was also of the same kind, nevertheless gave what seemed to be a less unsatisfactory age. Age, however, was no problem for the Lemaitre model, for here the cosmological term of Einstein's original model was involved once more, giving a repulsion which, after a certain point, began to take over from gravitation and so caused an increasing rate of expansion. Later, in the 1950s, the revision of the cosmic distance scale for galaxies by Walter Baade removed the age of the universe problems presented by the Friedmann and Einstein-de Sitter models, while the Lemaître model was modified by George Gamow and his colleagues Ralph Alpher and Robert Herman, to incorporate a hot **big bang** in which the universe was not only originally very dense but also very hot.

A model which avoided problems of the age of the universe entirely yet did not invoke the cosmological term was the **steady state** model, devised in 1948 by Hermann Bondi, Thomas Gold and Fred Hoyle (Fig. 8·11). It was based on what they called the 'perfect cosmological principle', namely that on the largest