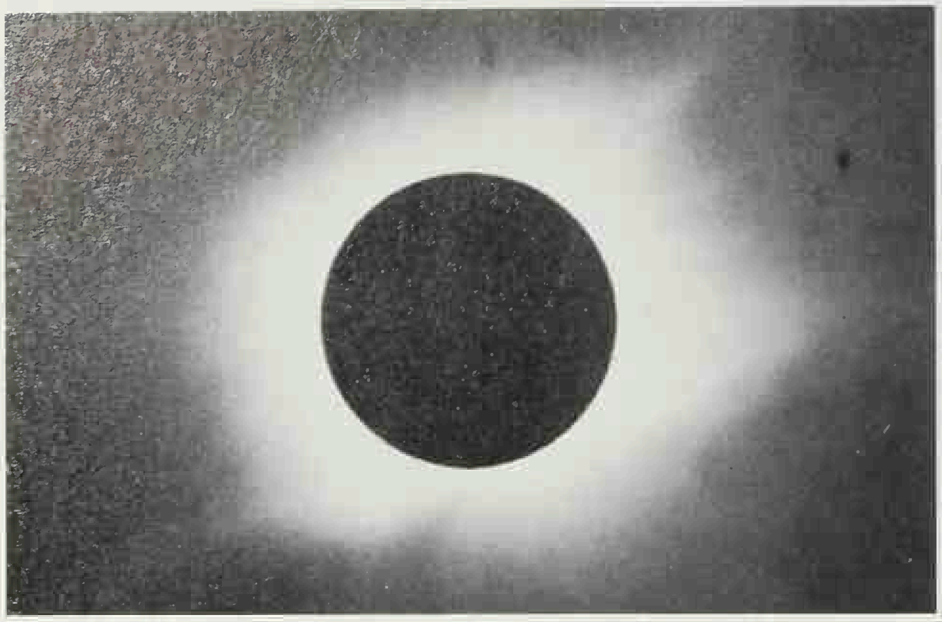

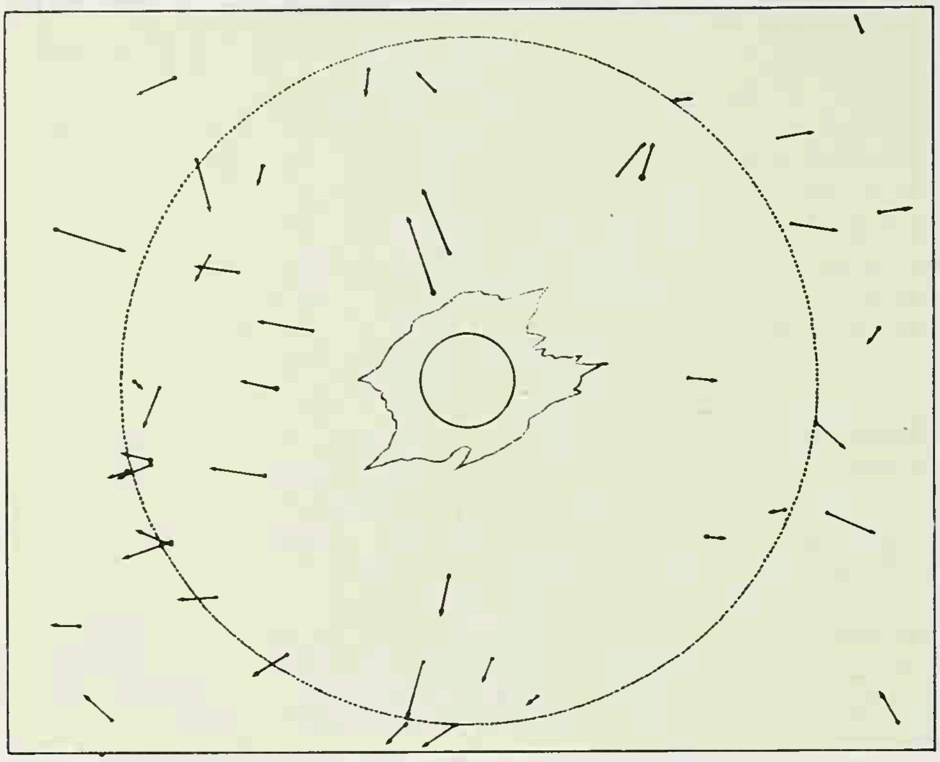

The 1922 September 21 total solar eclipse photographed from Wallal Downs, Western Australia. Similar plates were used to obtain the apparent shift of stars close to the Sun, and these are shown on the chart. Note that the scale of the chart (A) is very much smaller than that of the stellar displacements (B), with overall lengths representing 1 degree and 1 second of arc respectively.

Cosmological consequences of relativity

In determining redshifts and making measurements of the brightnesses and apparent diameters of galaxies, the curved space of general relativity results in different values to those which would be obtained if space were flat (Euclidean). For instance, in flat space the redshift is a straightforward quantity (page 196), such that if its value ever reaches 1, it shows that the body concerned is moving away with the velocity of light. In special relativity the formula for the redshift is more complex:

$$1 + z = \sqrt{(c+v)/(c-v)}$$

where z is the redshift. Here the value for the redshift can be much more than 1, reaching infinity for a velocity equal to the velocity of light. Relativistic redshift calculations have to be used for large redshifts, and in consequence we find quasars with redshifts of 2 and 3, or even nearly 4, a redshift of 2 indicating a velocity of recession at 80 per cent the speed of light. Not only does the redshift formula have to be changed in a relativistic universe, there is also the gravitational redshift to take into account.

The redshift plays its part in measurements of the apparent brightness of galaxies, since when present it reduces the apparent luminosity. Measurements of galaxy brightness will, therefore, all be underestimates unless a redshift correction is made, and a relativistic one is needed for all but the shortest distances. Perhaps one of the more unusual aspects of the effect on measurement of the relativistic universe is in the appearance of the diameter of distant galaxies. On Earth and in the nearer reaches of space, we are used to seeing the angular diameter of a source becoming less as it moves further away: the apparent angular diameters of the Sun, Moon and planets are smaller the further off they are. For example, as the relative positions of Venus and the Earth alter, the apparent diameter of Venus goes from almost 60 arc sec. when nearest, to less than 10 arc sec. when at its furthest. In curved space-time, this diminution of apparent angular diameter also occurs, but only up to a certain distance; after this the bending of light gives a similar effect to a lens and apparent angular diameters increase with distance. The distance at which this change occurs depends on the precise kind of relativistic universe we live in – a question to be discussed in a moment – but as an example, in the 'model' worked out by Einstein and Willem de Sitter the change happens at a distance of almost 5 000 Mpc.

Another very strange effect is the time dilation close to a black hole. A black hole, as we have seen (pages 73–75), emits no radiation and is called a hole because its excessive gravitational pull distorts space-time so much that it bends over on itself leaving the huge mass of material in what is virtually a hole in space-time. The material itself falls together so that it occupies no space and forms what is known in space-time as a singularity. Around the singularity there is a small spherical volume of space which acts as a boundary; inside this spherical boundary everything is crushed out of existence. As mentioned in Chapter 3, the gravitational field inside is so strong that an astronaut falling in feet first would be stretched out like a piece of spaghetti. We have already seen (page 74) that the radius of the sphere which forms this boundary, the Schwarzschild radius, depends on the amount of material inside. The condition under which a black hole exists is that the material of which it is composed must be highly concentrated: it has, in fact, an incredible density, so great that all the material in the Sun, which amounts to something of the order of 2×10^{27} tonnes, would have to be nearly 4×10^{16} times more concentrated. So great a concentration of mass causes the strange relativistic effect that we, outside the Schwarzschild radius, observe as time dilation. The space-time surrounding the region of the hole is so distorted, that at the Schwarzschild radius time is infinitely stretched out. We could, therefore, never see the astronaut fall into the black hole; he would appear to hover there for ever. It is for this reason that the sphere with the Schwarzschild radius is usually called the event horizon.