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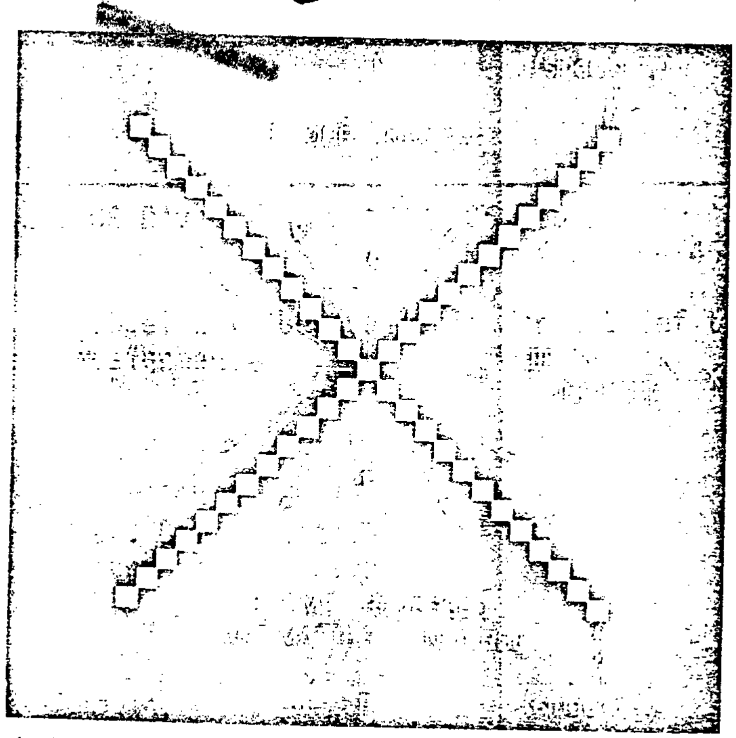
Is ours only one of three universes?

by Dietrick E. Thomsen



Space-time diagram of Gott's proposed three-universe cosmological model.

Gott/Astrophysical Journal

The usual big-bang cosmology connected with Einsteinian general relativity has the universe starting from a point of space-time that is called the singularity. "Singularity" is a mathematician's euphemism for something difficult to deal with, a point at which physically the universe has no dimensions and infinite density. From this point the universe expands as time proceeds, extending its dimensions and lowering its density.

Such is the usual picture of the expanding universe. But this universe occupies only one region of the space-ime that physicists are used to dealing vith, the region that lies to the future of the singularity. The question arises: What happens in the other regions of pace-time that physicists are able to magine? Does anything happen in the ingularity's past? Can anything happen eside it, so to speak in the regions of pace-time called spacelike?"

The answer, says J. Richard Gott III f California Institute of Technology, s yes. Writing in the latest ASTROPHYSICAL JOURNAL (Vol. 187 No. 1), he hows that if we look for the most genral solutions of Einstein's equations, flat space-time, we come up with ree universes. One is our own, which e have just described, lying in the ngularity's future and dominated by rdinary matter. Let us call it Universe Universe II lies in the singularity's ast and is dominated by antimatter. niverse III lies in the spacelike region space-time and is inhabited by tayons, particles that travel faster than ht.

To understand the geometry of this ther mind-boggling concept, it is necsary to spend a few words on a genal description of space-time. In true ace-time there are three spacelike nensions and one timelike dimension. r graphic purposes two of the space nensions are suppressed, and a twonensional graph is drawn in which vertical axis is time and the horintal space.

Every point in this two dimensional ace-time represents an event: It specis both the location and the time at ich something happens. The start of articular particle's flight may be one nt; its finish, another. The slope of line that joins them represents the ocity of the flight.

Calculation shows that the lines rung at 45 degrees to the time and space axes are of particular importance. They represent objects moving at the speed of light (they define what is called the light cone), and in ordinary physics one cannot cross them in going from event to event. The light lines (or the light cone in more than two dimensions) divide space-time into two regions, the timelike (in the upper and lower quadrants) and the spacelike in the right and left quadrants.

For two events in the timelike region (where we live) it is possible to find an observer moving in such a way that the two events seem separated in time only. If observer A sees a particle moving from x to y while the time goes from t_1 to t_2, observer B, who happens to be going along with the particle, will see the time change only. If the particle was in his hand at the start of the flight it will be in his hand at the end. In the spacelike region, in a similar way one can find an observer for whom two events are simultaneous but appear to represent an instantaneous translation in space. Thus in the spacelike region our usual perceptions of space and time and cause and effect are overthrown, but we need not worry about it since we can never get there.

When observer B moves with respect to observer A, from A's point of view the motion represents a skewing of his time axis in the direction of the light line. It can also be shown that his space axis will skew and also in the direction of the light line. The faster B goes, the narrower becomes the angle between his space and time axes. When he reaches the speed of light his space and time axes meet in a grand flash of—well that's the singularity, as Gott considers it.

There's no crossing it. Gott puts our universe in the upper quadrant to the future of the singularity. His time-reversed antimatter universe lies in the lower quadrant to its past. And his tachyon universe lies in the spacelike region, which is not two regions but one. This can be seen if we add a third dimension and imagine the diagram rotated around the time axis: Regions I and II become cones; region III becomes a wedge-shaped ring.

There is no communication across the singularity. Antimatter and tachyons can exist in our universe occasionally and ephemerally—they are not visitors from the other universes. They are produced here. There are differences in perception: Our view of Universe II, if we could see it, would be that it is dominated by matter and contracting. To its own inhabitants it looks as if antimatter dominates and it is expanding. Finally the principal of causality, which says that neither information nor energy can be transmitted faster than light, is not violated in the tachyon universe. Though the tachyons themselves go faster than light, their radiation, which is the only way they can transmit energy or information, does not.

Gott concludes: "The model we have presented is a unified, time-symmetric model treating matter, antimatter and tachyons in a natural and equal fashion. The model is consistent with our present observations of the universe and could gain support from an experimental discovery of tachyons. . . ." □

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11.6 Proper Time and the Light Cone

In the previous sections we have explored some of the physical consequences of the special theory of relativity and Lorentz transformations. In the next two sections we want now to discuss some of the more formal aspects and to introduce some notation and concepts which are very useful in a systematic discussion of physical theories within the framework of special relativity.

In Galilean relativity space and time coordinates are unconnected. Consequently under Galilean transformations the infinitesimal elements of distance and time are separately invariant. Thus

$$\left.\begin{aligned} ds^2 &= dx^2 + dy^2 + dz^2 = ds'^2 \\ dt^2 &= dt'^2 \end{aligned}\right\} \qquad (11.59)$$

For Lorentz transformations, on the other hand, the time and space coordinates are interrelated. From (11.21) it is easy to show that the invariant "length" element is

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2\,dt^2 \qquad (11.60)$$

This leads immediately to the concept of a Lorentz invariant *proper time.* Consider a system, which for definiteness we will think of as a particle, moving with an instantaneous velocity $\mathbf{v}(t)$ relative to some coordinate system K. In the coordinate system K' where the particle is instantaneously at rest the space-time increments are $dx' = dy' = dz' = 0$, $dt' = d\tau$. Then the invariant length (11.60) is

$$-c^2\,d\tau^2 = dx^2 + dy^2 + dz^2 - c^2\,dt^2 \qquad (11.61)$$

In terms of the particle velocity $\mathbf{v}(t)$ this can be written

or $dt = \gamma d\tau$

$d\tau^2 = -\left(\frac{dx^2}{c^2} + \frac{dy^2}{c^2} + \frac{dz^2}{c^2}\right) + dt^2$

$$d\tau = dt\sqrt{1 - \frac{v^2}{c^2}} \qquad (11.62)$$

$d\tau = \frac{dt}{\gamma}$

Equation (11.62) shows the time-dilatation effect already discussed. But much more important, by the manner of its derivation (11.62) shows that the time τ, called the *proper time of the particle*, is a Lorentz invariant quantity. This is of considerable importance later on when we wish to discuss various quantitie nd their time derivatives. If a quantity behaves in a certain way und ntz transformations, then its proper time

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JOHN DAVID JACKSON
JOHN WILEY & SONS 1962

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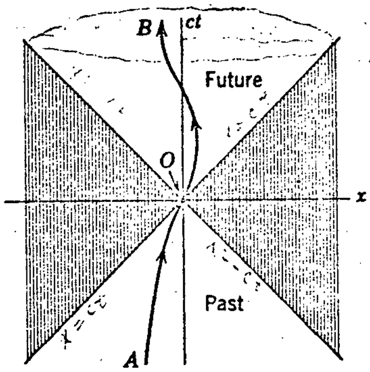

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Fig. 11.10 World line of a system and the light cone. The unshaded interior of the cone represents the past and the future, while the shaded region outside the cone is called "elsewhere." A point inside (outside) the light cone is said to have a time-like (space-like) separation from the origin.

derivative will behave in the same way because of the invariance of $d\tau$. But its ordinary time derivative will not have the same transformation properties. From (11.62) we see that a certain proper time interval $(\tau_2 - \tau_1)$ will be seen in the system K as a time interval

$\gamma \Delta t' = \Delta t$
$\gamma \Delta \tau = \Delta t$

$$t_2 - t_1 = \int_{\tau_1}^{\tau_2} \frac{d\tau}{\sqrt{1 - \dfrac{v^2(\tau)}{c^2}}} \tag{11.63}$$

where t_1 and t_2 are the corresponding times in K.

Another fruitful concept in special relativity is the idea of the light cone and "space-like" and "time-like" separations between two events. Consider Fig. 11.10, in which the time axis (actually ct) is vertical and the space axes are perpendicular to it. For simplicity only one space dimension is shown. At $t = 0$ a physical system, say a particle, is at the origin. Because the velocity of light is an upper bound on all velocities, the space-time domain can be divided into three regions by a "cone," called the *light cone*, whose surface is specified by $x^2 + y^2 + z^2 = c^2t^2$. Light signals emitted at $t = 0$ from the origin would travel out the 45° lines in the figure. But any material system has a velocity less than c. Consequently as time goes on it would trace out a path, called its *world line*, inside the upper half-cone, e.g., the curve OB. Since the path of the system lies inside the *upper half-cone* for times $t > 0$, that region is called the *future*. Similarly the *lower half-cone* is called the *past*. The system may have reached O by a path such as AO lying inside the lower half-cone. The shaded region outside the light cone is called *elsewhere*. A system at O can never reach or come from a point in space-time in elsewhere.

The division of space-time into the past-future region and the elsewhere region can be emphasized by considering the invariant separation between two events $P_1(x_1, y_1, z_1, t_1)$ and $P_2(x_2, y_2, z_2, t_2)$ in space-time:

$$s_{12}^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2 - c^2(t_1 - t_2)^2 \tag{11.64}$$

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For any two events P_1 and P_2 there are two possibilities: (1) $s_{12}^2 > 0$, (2) $s_{12}^2 < 0$. If $s_{12}^2 > 0$, the events are said to have a space-like separation, because it is always possible to find a Lorentz transformation to a new coordinate system K' where $(t_1' - t_2') = 0$ and

$$s_{12}^2 = (x_1' - x_2')^2 + (y_1' - y_2')^2 + (z_1' - z_2')^2 > 0 \qquad (11.65)$$

That is, the two events are at different space points at the same instant of time. In terms of Fig. 11.10, one of the events is at the origin and the other lies in elsewhere. If $s_{12}^2 < 0$, the events are said to have a time-like separation. Then a Lorentz transformation can be found which will make $x_1' = x_2'$, $y_1' = y_2'$, $z_1' = z_2'$, and

$$s_{12}^2 = -c^2(t_1' - t_2')^2 < 0 \qquad (11.66)$$

In the coordinate system K' the two events are at the same space point, but are separated in time. In Fig. 11.10, one point is at the origin and the other is in the past or future.

The division of the separation of two events in space-time into two classes—space-like separations or time-like separations—is a Lorentz invariant one. Two events with a space-like separation in one coordinate system have a space-like separation in all coordinate systems. This means that two such events cannot be causally connected. Since physical interactions propagate from one point to another with velocities no greater than that of light, only events with time-like separations can be causally related. An event at the origin in Fig. 11.10 can be influenced causally only by the events which occur in the past region of the light cone.

11.7 Lorentz Transformations as Orthogonal Transformations in Four Dimensions

The Lorentz transformation (11.19) and the more general form (11.21) are linear relations between the space-time coordinates (x, y, z, t) and (x', y', z', t'), subject to the constraint,

$$x^2 + y^2 + z^2 - c^2t^2 = x'^2 + y'^2 + z'^2 - c^2t'^2 \qquad (11.67)$$

This constraint is very reminiscent of the constraint involved in the rotation of coordinate axes in three space dimensions. In fact, if we introduce the four space-time coordinates,

$$x_1 = x, \quad x_2 = y, \quad x_3 = z, \quad x_4 = ict \qquad (11.68)$$

then the constraint becomes

$$R^2 = x_1^2 + x_2^2 + x_3^2 + x_4^2 \qquad (11.69)$$

$R^2 = R'^2$