risk is not simply measured by the product of probability times consequences. It is for this reason that I believe the maximum consequences of reactor accident, as well as the risk, must be adequately low. The evidence on iodine release from water reactor accidents suggests that consequences may already be overestimated.

As for Professor Brown's grisly suggestion, I don't understand why he confines his offer to an old nuke like me when proponents of any energy technology (including so-called benign technologies) can, if one applies the logic implied in Professor Brown's suggestion, be held responsible for the many thousands of random deaths each year caused by any technology that transforms energy from one form in another.

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Relativity and field theory

Jacob Bekenstein's response (January, page 69) to a letter by Michael Brill and Winfield Salisbury shows significant misunderstandings of a theory proposed by me. The purpose of this letter is to clarify the misunderstandings and to point out that not only is the theory in agreement with all known experiments, but it has a compelling simplicity and inner consistency of its own which can compare with those of other existing theories of gravitation.

Consider two rooms, one in free space being pulled with acceleration g, the other resting on the surface of the earth where the gravitational acceleration is g. In the first room a piece of iron and an apple (let go from rest) hit the floor at the same time because the floor is going up toward the iron and the apple. In the second room the same piece of iron and the apple (again let go from rest) hit the floor at the same time because they are moving down with the same acceleration g. In this *kinematical* sense the new theory works the same way as any other theory of gravity where the equations of motion are independent of mass.

The difference, and in fact part of the motivation, of the new theory comes from the following *dynamical* question: Will the dents on the floors (caused by the iron) be also exactly the same? To see why the question arises, note that in the first room we would naturally think of the effect as depending only on potentials definable within the room (say, from the floor to a height), whereas, in the second room an overall potential due to the presence of the earth could cause a change in the energy (mass) of the iron. So in the second room there is the possibility that the mass m might become αm. The equations of motion would not be affected (they are independent of mass) but the dents on the floor would be different because now mass is αm instead of m. This possibility cannot be removed by appealing to tidal forces and so on, because the two rooms might be sitting on two identical planets one of which has an outer shell (enclosing the room), causing no change in g but contributing additional energy (mass) to the iron. Motions would be identical but energy–momenta could differ because of this extra potential. (Such a difference would also have a detectable quantum mechanical effect since, say, for a neutron, the phase difference between two heights would be $\alpha\delta$ instead of just δ.)

The new theory eliminates such distinctions by formulating the problem of dynamics so that: 1) The metric depends only on potential differences as $g_{\mu\nu}(\tilde{\phi} - \tilde{\phi}')$; that is, the metric displays a *group property* with respect to potentials. 2) The tensor potential $\tilde{\phi} = \phi_\mu{}^\nu$ is a generalization of the Newtonian potential; it is symmetric and satisfies the covariant *d'Alembert equation* of the same metric, $\tilde{\phi}'$ being its integration constants. 3) The group property is assumed *multiplicative* and the gravitational red-shift $\nu' = \nu e^{-(\phi - \phi')}$, where $\phi = -\frac{1}{2}\log(g_{00})$ is used as a *correspondence condition*. (The red-shift was recently tested,[1] in this form, to a high accuracy of 2.5×10^{-6}.) These conditions plus the relativistic requirement that all space–time variables must be treated *on equal footing* determines the form of the metric to be an exponential. (The usual theory satisfies a similar group property but only on g_{00}. One of the field equations, $R_0{}^0 = 0$, is exactly the general Laplace equation[2] of $\phi = -\frac{1}{2}\log(g_{00})$ in the static Schwarzchild metric. Note also that in a 1907 article[3] Einstein insisted "in all strictness" (his words) on the exponential character of time-dilation, $t' = t\exp(\gamma\xi/c^2)$, where $\gamma\xi/c^2$ is a special case of our $\phi - \phi'$.) The metric thus is

$$g_{\mu\nu} = (\tilde{\eta} e^{2(\phi - 2\tilde{\phi})})_{\mu\nu}$$

where $\tilde{\eta}$ is the Lorentz metric and $\phi = \phi_\mu{}^\mu$, the trace.[4] (Note that in first order this exponential gives the linearized Einstein metric.) The static field corresponds to $\tilde{\phi} \to \phi_0{}^0 = \phi(x, y, z)$, hence the static line element is

$$ds^2 = e^{-2\phi}dt^2 - e^{2\phi}(dx^2 + dy^2 + dz^2)$$

where $\phi = M/r$ is the solution of the Laplace equation of the same line-element. This line-element is known to be in agreement with all experiments having to do with a static field. Likewise when effects having to do with other components are considered (first

and second order in $\tilde{\phi}$) the general metric is again found to be in complete agreement with experiments. Only two questions were ever raised about this theory and each is due to a misunderstanding.[5] [In the first instance the scalar ϕ was taken as the whole gravitational field, whereas, it is only the scalar trace of the more general field $\tilde{\phi}$. In the second instance a conjecture made to represent the most general solution of the field equations was assumed to be an essential part of the theory, whereas, it only means that the most general solution of the field equations is not known. The conjecture itself is never proven or disproven because a prescription of how to expand the metric beyond second order (when certain terms do not commute) is missing. But, of course, this is only a mathematical problem which, by the way, the usual theory also has.]

Completion of this theory into a more recognizable framework is very simple. The theory is given by just three equations:

$$R_\mu^\nu - \tfrac{1}{2}\delta_\mu^\nu R = 2(\Box^2\phi_\mu^\nu + t_\mu^\nu) \qquad (1)$$

$$\Box^2\phi_\mu^\nu = 4\pi\sigma u_\mu u^\nu \qquad (2)$$

$$\frac{du_\mu}{ds} = \tfrac{1}{2}\partial_\mu g_{\alpha\beta}u^\alpha u^\beta \qquad (3)$$

Equation 1 is obtained from the metric by computing the Einstein tensor. It is shown that closed forms obtainable from the exponential always lead to this form. As such equation 1 is just another way of writing the exponential. Here $\Box^2$ is the covariant d'Alembertian and the form of $t_\mu{}^\nu$ is exactly that of a standard field stress-energy of $\tilde{\phi}$ and its trace ϕ. Since such a $t_\mu{}^\nu$ is interpretable as a *field stress-energy*, the remaining part, $\Box^2\phi_\mu{}^\nu$, identifies the *matter stress-energy* which is equation 2. This equation is as in other field theories of physics where the fields are related to the source. In this case the source is

$$\tau_\mu^\nu \rightarrow \sigma u_\mu u^\nu$$

When $\tau_\mu{}^\nu = 0$ the field satisfies a d'Alembert equation which is our original assumption. (In the usual theory the right handside of the field equations is everything *except* the gravitational field stress–energy. In the new theory it is everything *including* the gravitational field stress–energy. Thus in the new theory the gravitational field stress–energy contributes to space–time curvatures on equal footing with matter stress–energy.) Equation 3 gives the geodesic equations of motion which depend only on $g_{\mu\nu}$. Thus we can put equation 2 into equation 1 which become our (geometric) field equations. Interestingly, for these equations we already have the solu-

tions we need. Therefore the only thing we have to do is to form the geodesic equations and calculate the motions of particles. It is further found[6] that one has

$$D_\nu t_\mu^{\ \nu} = \sigma \partial_\mu g_{\alpha\beta} u^\alpha \mu^\beta / 2$$

which is σ times the right hand side of the geodesic equations. This completes the field-theory interpretation because the equations of motion can now be written,

$$\sigma du_\mu / ds = D_\nu t_\mu^{\ \nu},$$

exactly as in field theory. The whole process is generally covariant because the equations are kept, at every stage, form-invariant, that is, coordinate-independent.

The net result of this simple theory of gravitation is that the structure of the space-time physics is turned into a standard field theory of spin-2 particles, although in a space curved partly by its own stress-energy. Several of its desirable features are worthy of special notice. We mention below a few that are easily provable on the simple static metric:

▶ A particle with zero rest-mass has a unique signal velocity $v = V = v_g = c(x) = ce^{-2\phi}$ for *all* wave lengths;[7] v, V, v_g being the particle, phase, and group velocities. This allows a unique operational procedure of space–time measurements for both waves and particles.

▶ With $\phi \to \phi - \phi'$ the metric is scaled but the scaled metric is still a solution of the original field equations. Thus $x \to x'$, where x' is the point of observation, leads to a "local" Lorentz metric $g_{\mu\nu} \to \eta_{\mu\nu}, c(x) \to c$, although the frame is still non-inertial (not freely falling). Thus in this theory the *observed* value of the velocity of light is always c as in special relativity.

▶ For a particle with nonzero rest-mass $v = v_g, vV = c^2(x) \to c^2$, also as in special relativity. This permits a generalization of quantum mechanics of particles from flat to curved space–times and thereby allows a detailed analysis of some quantum gravity experiments.[7]

▶ With gauge $c(x) \to c$, the $t_\mu^{\ \nu}$ turns out to be a true tensor, not eliminable with any coordinate transformation consistent with that gauge, and reduces *exactly* to the Newtonian field stress–energy of a static gravitational field.

▶ In the strong field limit the theory does not possess an event horizon[4] and does not lead to black-hole behavior as can also be seen from the refractive index analogy $n = e^{2\phi}$. Radially directed light will always escape (red-shifted).

It is clear that the theory displays a compelling simplicity and promise and is close to Einstein's original direction of formulating the geometric theory in close correspondence with special relativity. The theory is compatible with a strong principle of equivalence, the wave–particle duality of quantum mechanics ($v = v_g \leftrightarrow$probability postulate), the symmetry of space–time variables, gauge theory, operational procedure of space–time measurements and a local field-theory interpretation of space–time geometry. Due to these a synthesis of space–time with quantum mechanics seems to be possible. The conventional theory is 65 years old and still it has not yielded to such a synthesis.

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Radio interferometry

Search and Discovery in March (page 21) contains a nice discussion of transcontinental radio interferometry. However, the statement that "No other astronomical technique—existing or proposed—can come within two orders of magnitude of such resolving power" (that is, a fraction of a milli-arcsecond) is not true.

In March 1981, I attended a conference sponsored by the European Southern Observatory on "The Scientific Importance of High Angular Resolution Observations in Optical and Infrared Astronomy." It is clear that the Europeans and, to a lesser extent, the Americans are now achieving high angular resolutions at infrared and optical wavelengths. A 4000-km radio interferometer operating at 1-cm wavelength has the same resolving power as a 400-m optical interferometer at 1 μm wavelength. A French group is currently using a 35-m optical interferometer and has measured double star separations and stellar angular diameters at the 1 milli-arcsecond level. They are now constructing a new interferometer with 10 times this baseline that may produce fringes within a year or two. Various other groups are considering construction of optical interferometers with comparable baselines. There is even a Swedish effort,