

On the Possibility of Discovering Reflectors or Absorbers of Gravity and of Constructing Effective Sources of Gravitational Waves

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It is well known that present-day theory predicts the impossibility of shielding against static gravitational fields by methods comparable to that of shielding against electrostatic fields by a Faraday cage. The reason for this is that the present-day theory denies the possibility of making matter of negative mass. The theory also predicts interactions between matter and non-static gravitational fields so weak that matter for all practical purposes would be transparent to gravitational waves, making gravitons unobservable.

This theory reflects what until now is known experimentally about gravity and matter. If gravity would have properties unknown as yet to mankind, these properties would have to be found experimentally, thus forcing theoreticians to change their theories and to adjust them to facts found against their expectations.

How could one perform experiments by which to discover absorption or reflection of gravitational waves in measurable amounts? As in experiments on absorption or reflection of light or of radiowaves, one needs (a) a source of radiation, and (b) a detector. Substances to be tried on gravito-absorbing or reflecting power can then be placed in between.

Before one can detect gravitational radiation, one first must create this radiation. Suppose there existed some extraordinary material with a much stronger interaction with non-static gravitational fields per gram of its weight, then theoreticians would predict. Sources as well as detectors of gravity radiation made out of such materials if they exist would be the most effective ones. But finding such materials if they exist would be a haphazard business, and when an effect were found, one would not even know whether one would be observing an effect of gravitational radiation

or of something else.

One would know how to operate with gravitational radiation if the source were made out of conventional materials satisfying existing gravitational theories. Therefore the task of this essay is to discuss whether one can theoretically expect to be able to build an effective gravity radiator out of normal matter.

Calculations of gravity radiation have been made in the past on the basis of Einstein's gravitational theory.¹ In contrast to them, we have based our present calculations on a new, Lorentz-covariant, linear theory of gravitation recently developed by Belinfante and Swihart.² Although theoreticians are tempted to prefer Einstein's theory to this new theory of Belinfante and Swihart, there are as yet no convincing direct experimental proofs that Einstein's theory is better than the new one. The latter explains Mercury's perihelion motion and the deflection of light rays passing along the sun equally well if not better than Einstein's theory; it yields the same gravitational red shift as Einstein's theory, and also explains the validity of the principle of equivalence of gravitational and of inertial mass.

The gravitational field is given by the retarded action caused by the matter sources. The effects of the latter sources have been expanded in powers of v/c , where v is the velocity of the source. We neglect all powers higher than second in v/c .

We first calculate the Wiechert-Liénard-type gravitational potentials. From the latter we derive the gravitational energy density and energy flux away from the source. The entire density tensor for this purpose is derived according to conventional field-theoretical methods.³ We calculated these quantities in the so-called "wave zone", by neglecting terms in energy density and flux dropping off with distance faster than r^{-2} .

Choosing the constants of the theory for maximum similarity to Einstein's experimental predictions,⁴ we find the following expression for the outward gravitational energy flux S in the wave zone in the field around a "rotator" with all masses concentrated on a line rotating with an angular velocity ω in a plane:

$$S = C[(\cos \theta)^2 + \frac{1}{4}(\sin \theta)^4(\sin 2\omega t)^2] - B(\sin \theta)^2(\cos 2\omega t).$$

Here, θ is the angle between the direction in which the flux is observed, and the axis around which the linear rotator is turned; t is the time of observation measured from an instant at which the linear rotator is seen perpendicular to the line of sight. If E is the non-relativistic kinetic energy of the rotator, and m is its (rest) mass, if $G = 6.67 \times 10^{-8} \text{ cm}^2 \text{ g}^{-1} \text{ sec}^{-2}$ and $c = 3.00 \times 10^{10} \text{ cm/sec}$, then C and B are given, at a distance r from the rotator, by

$$C = 4G\omega^2 E^2 / \pi r^2 c^5, \quad B = C(mc^2 + E) / E$$

Therefore, the term with B is much larger than the one with C as $E \ll mc^2$. Notice that this term with B fluctuates in sign, causing "large" gravity currents to and from the source with half the period of the rotation. This is a peculiarity of the Belinfante-Swihart theory, and is the reason for our particular interest in this theory in connection with the question of observability of gravitational radiation. When and where the energy flux becomes negative, this is not due to a flowing back of gravitation, but the energy density there is negative, corresponding to an emission of negative-energy gravitons into two quadrants of space around the axis of rotation while positive-energy gravitons are emitted into the other two quadrants. These four quadrants rotate together with the rotator, thus at a fixed direction in space causing two periods of fluctuation of the energy current as the rotator turns around once. Superimposed on this strong fluctuating energy current is a weak positive flux of energy comparable to what Einstein's theory would predict. Only this steady flux with coefficient C contributes to the net loss of energy by the rotator. The question, however, arises whether the much stronger currents of gravitons of alternately positive and negative energy could not be observed.

Assuming that the gravitons each have an energy $h\nu = h\omega/2\pi$, we can estimate the number of gravitons radiated per cm^2 per sec by $n = 2\pi S/h\omega$. Neglecting for $E \ll mc^2$ the term with C in the expression for S , we find S maximum in the equatorial plane $\theta = 90^\circ$. At times of maximum intensity of the energy flux as ωt is a multiple of $\pi/2$, we find here $[S] \approx B$, so that here n reaches the maximum value of

$$n_{\max} \approx 8G\omega E m / r^2 c^3 h$$

For a source to be used in the laboratory, consider a steel rod, specific gravity ρ , cross sectional area A , length $2L$, and assume it can be rotated so fast as to cause a central stress T nearing the tensile strength of steel, say about 50,000 lb/sq.in., so $T \approx 3.5 \times 10^9$ dyne/cm². For $\rho \approx 8g/cm^3$, this would require a linear velocity $V \sim 3 \times 10^4$ cm/sec at the ends of the rod. The angular velocity then is $\omega = L^{-1}(2T/\rho)^{1/2}$, and the maximum number of gravitons then emitted per steradian per second in the optimum directions is

$$n_{\max} r^2 \approx [2\rho T^3]^{1/2} (32GA^2 L / 3c^3 h).$$

For a 5cm x 5cm x 80cm steel rod, ($A = 25cm^2$, $L = 40cm$, $\rho = 8g/cm^3$) this gives about 82 million gravitons per second per steradian. As $\omega \sim 750sec^{-1}$, we assumed here our ability to rotate this 35lb. rod at over 7000 rpm. For the energy per graviton we took here $h\nu \sim 8 \times 10^{-25} erg$, corresponding to a wavelength $\lambda \sim 2500km$. The

optimum energy flux then amounts to 6.4×10^{-17} erg per steradian per second = 4×10^{-6} electron volt per steradian per second. Even if some extraordinary material existed which would be super-sensitive for gravitational radiation, it is hardly imaginable that it would be sensitive enough for detecting such tiny energy fluxes.

Now, consider a source of astronomical dimensions; for instance, the double star *Capella* (α Aur.). In this case we have $r = 4.9 \times 10^{19} cm$, $\theta = 40^\circ$, $m = 1.5 \times 10^{34} gram$, $E = 1.5 \times 10^{47} erg$, $\omega = 7.0 \times 10^{-7} sec^{-1}$. This yields for the number of gravitons reaching the earth per cm^2 per second:

$$n = [1.2 \times 10^{16} + 0.09 \times 10^{16} (\sin 2\omega t)^2 - 7.8 \times 10^{23} \cos 2\omega t] cm^{-2} sec^{-1}.$$

The fluctuating term with factor 10^{23} has a period of 52 days. Even this fluctuating term corresponds to a very weak energy current of $-5.7 \times 10^{-10} (\cos 2\omega t) erg cm^{-2} sec^{-1}$, due to the smallness of the energy per graviton ($\sim 7.4 \times 10^{-34} erg$). The quantum character of waves containing so many and so small quanta is completely lost; even the wave nature is nearly lost as the wavelength of these waves is $\lambda = 2\pi/\omega \approx 2.7 \times 10^{17} cm \approx 0.29$ lightyears. Fields of this nature will be experienced as slowly varying gravitational fields superimposed on the much stronger Newtonian fields resulting from sun, moon, and planets, and therefore will go unnoticed.

The other extreme is a source of atomic dimensions. For a hydrogen atom we find for the optimum radiation per steradian $S_{\max} r^2 \approx 10^{-43} erg/sec$, if we may believe that the classical formula, on account of the correspondence principle, gives a fair approximation. Again this seems too little for observation.

We conclude that sources made out of conventional materials do not provide gravitational radiation strong enough for practical use in experiments on absorption or reflection of gravity waves, even if we assume the existence of the relatively "strong" energy fluxes predicted by the Belinfante-Swihart theory of gravitation. The only possibility remaining for such experiments then seems to be a haphazard trying out of various materials in the hope that some will refute theory by emitting much stronger gravity waves than predicted. There is, however, no theoretical ground for such hope. Also, if some material *would* send out unusually strong gravity waves, there is little hope that the experimenter will become aware of this. For these reasons it will be hard to convince scientists of the usefulness of spending their time on such experiments. Yet, such experimentation necessarily will have to precede all attempts at practical applications of reflection or absorption of gravity.

REFERENCES

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2. F. J. Belinfante and J. C. Swihart, *A Theory of Gravitation and Its Quantization*, Report of Research Supported by The National Science Foundation and the Purdue Research Foundation, Purdue University, Lafayette, Indiana, September 1954. This study and its later extension by F. J. Belinfante are now being prepared for publication, probably in the *The Physical Review*.
3. F. J. Belinfante, *Physica* 6, 887 (1939); 7, 449 (1940).
4. We consider here case Ia on Page 75 of Reference 2.