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Gravity-induced electric polarisation near the Schwarzschild limit

It has long been recognised that besides carrying the fundamental unit of charge an electron is also endowed with inertia. Only recently has attention been paid to the possibility that phenomena may exist which depend on the gravitational mass[1]. Here we point out that strong gravitational fields, such as those encountered in collapsed stellar objects, may produce observable electromagnetic effects arising directly from the gravitational mass of electric charges.

Some sixty years ago Tolman and Stewart[2] described an experiment in which the inertia of electrons is revealed. This involved a conductor, such as a circular horizontal wire, which oscillates about a vertical through its centre. Because of their inertia the free electrons will move relative to the crystal structure of the wire and so an oscillating current will be generated. To a first approximation, if **a** is the acceleration of the wire at any instant, then as far as the free electrons are concerned an effective electric field **E** given by

$$\mathbf{E} = \left(\frac{m}{e}\right)\mathbf{a} \tag{1}$$

is present in the reference frame of the wire (m and e are the electronic mass and charge, respectively). In principle a method for obtaining the specific charge e/m was made available.

From the point of view of relativity theory, we may regard the acceleration of the wire as equivalent to the action of a gravitational field (of oscillatory character in the above case), in accordance with Einstein's principle of equivalence. In fact whenever a conductor is held in a gravitational field **g** we may expect an effective electric field

$$\mathbf{E} = -\left(\frac{m}{e}\right)\mathbf{g} \tag{2}$$

to be manifested to the free electrons. In this case m is the electron's gravitational mass, indistinguishable from the inertial mass in the light of the equivalence principle.

If this is the effect of gravitation on free electrons (admittedly a very small one in the gravitational field of the Earth) then a corresponding phenomenon must influence bound charges in a dielectric. We may think of this as a gravitational polarisation

$$\mathbf{P} = \chi\,\mathbf{E} = -\chi\left(\frac{m}{e}\right)\mathbf{g} \tag{3}$$

where χ is the gravitational susceptibility of the dielectric. If indeed **P** exists then, as in ordinary electric polarisation, an equivalent volume distribution of charge $-$ div. **P** and surface distribution **P.n** would result in accordance with conventional analysis.

For the gravitational field of the Earth such a polarisation no doubt produces extremely small consequences. But in a collapsed star lying near to its Schwarzschild limit the local value of **g** may be large enough to produce observable effects, especially in conjunction with a rapid rotation of the star[3]. Thus if we apply the usual Schwarzschild metric to a condensed object then the local value of the gravitational intensity on the surface $R = R_S$ is given by

$$g = (GM / R_S{}^2)\;(1 - [2\,GM/(c^2 R_S)]^{-\frac{1}{2}} \tag{4}$$

M being the total mass and G the Newtonian gravitational constant. Here g is the proper acceleration (invariant) of a freely falling test particle relative to the fixed surface, and is equal to the magnitude of the first curvature vector of the world line of an atom fixed under stress at $R = R_S$. Equivalently g is the acceleration (in the opposite direction) of the fixed atom relative to a freely falling geodesic frame instantaneously at rest at $R = R_S$. Clearly if $R_S = R^*$, where $R^* = 2GM/c^2$ (the Schwarzschild gravitational radius) g may become extremely large, with corresponding intensification of the effects we have described on free and bound electric charges. Even in a neutron star (the limiting consequence of these effects) there will be such charges near the surface.

We now consider in particular what happens to a 'standard clock' S located in such intense gravitational fields. If the standard clock is an atomic emission line then we cannot expect this to be at the standard laboratory frequency in such circumstances. There must necessarily be an effect related to the electric Stark phenomenon. For example although the usual redshift formula will apply to the emitted radiation as received by a remote observer O, it is not sufficiently realised that this formula gives only the ratio ν_S / ν_0 for the frequencies emitted and observed in terms of the change in the gravitational field between S and O. It tells us nothing about the emitted frequency absolutely. The emitted frequency will in fact be standard only for an atom in free fall, or when the gravitational field is negligible. It is usually assumed in the case of the Sun, for example, that these conditions prevail. But clearly the assumption is invalid when we consider an atom fixed on the surface of a highly condensed object.

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Meteorological features affecting large aperture synthesis radio telescopes

Variations of atmospheric radio refractive index can cause phase differences between signals received at spaced aerials and limit the resolution of large radio telescopes using the aperture synthesis technique[1]. Hinder[2] found that anomalous phase differences recorded at the One-Mile telescope at Cambridge[3] were caused by thermal updraughts and fair weather cumulus; the mean size of the irregularities was 700 m. Earlier calculations[4] had shown that the gradients of refractive index across fronts were likely to be important but it was believed that corrections using ground-based measurements of pressure, temperature, and humidity could be applied to reduce errors from such large scale (≈ 500 km) weather systems[5].

The first few months of observing with the 5-km telescope at the Mullard Radio Astronomy Observatory, University of Cambridge, showed that there were frequent significant effects from intermediate systems, with scales of 10 to 100 km or more. An investigation was undertaken to relate these periods of anomalous phase changes—'events'—to meteorological phenomena and the results are summarised here.

Telescope operational periods (excluding those spent observing complex emitting regions) event times to within 1 h and event intensities, for part of May, June to September, and