ve have

$$= \tfrac{1}{2}m_1v_1^2+\tfrac{1}{2}m_2v_2^2+\frac{1}{8c^2}(m_1v_1^4+m_2v_2^4) \qquad (2)$$

$$\frac{m_1m_2}{r}-\frac{Gm_1m_2}{2rc^2}[\mathbf{v}_1\cdot\mathbf{v}_2+(\mathbf{v}_1\cdot\mathbf{n})(\mathbf{v}_2\cdot\mathbf{n})-3(\mathbf{v}_1-\mathbf{v}_2)^2]$$

$$-\frac{G^2m_1m_2(m_1+m_2)}{2r^2c^2} \qquad (3)$$

$$-V_{\mathrm{D}}=-\frac{e_1e_2}{r}+\frac{e_1e_2}{2rc^2}[\mathbf{v}_1\cdot\mathbf{v}_2+(\mathbf{v}_1\cdot\mathbf{n})(\mathbf{v}_2\cdot\mathbf{n})] \qquad (4)$$

$$_{\mathrm{M}}=\frac{G}{2r^2c^2}[2e_1e_2(m_1+m_2)-(e_1^2m_2+e_2^2\,m_1)] \qquad (5)$$

a unit vector along $\mathbf{r}_1-\mathbf{r}_2$.

tence of a gravitational analogue of the magnetic Gv_iv_j terms) is now apparent. It is instructive, sider, as in refs 1 and 2, the two particles to be in their rest frames, from the balance of and Coulomb forces. Then, we consider a frame of n which the particles, while maintaining the same part, are moving with uniform velocity $\mathbf{v}_1=\mathbf{v}_2\equiv\mathbf{v}$ $=\mathbf{v}_2\cdot\mathbf{n}=0$. Thus

$$L_0=\tfrac{1}{2}(m_1+m_2)v^2+\frac{v^4}{8c^2}(m_1+m_2) \qquad (6)$$

$$_{\mathrm{EIH}}=\frac{Gm_1m_2}{r}\left(1-\frac{v^2}{2c^2}\right)-\frac{G^2m_1m_2(m_1+m_2)}{2r^2c^2} \qquad (7)$$

$$-V_{\mathrm{D}}=-\frac{e_1e_2}{r}\left(1-\frac{v^2}{2c^2}\right) \qquad (8)$$

responding 'generalised force' on particle 1 from is

$$\left.\frac{L}{\mathbf{r}_1}\right)\Bigg|=-\frac{Gm_1m_2}{r^2}\left(1-\frac{v^2}{2c^2}\right)+\frac{G^2m_1m_2(m_1+m_2)}{r^3c^2}$$

$$1-\frac{v^2}{2c^2}\Bigg)-\frac{G}{r^3c^2}\left(2e_1e_2(m_1+m_2)-(e_1^2m_2+e_2^2m_1\right) \qquad (9)$$

ne condition for equilibrium in the moving frame is ^2m_i. In other words, as previously noted[5,6] we have condition for equilibrium in the general relativistic the Newtonian case. In addition, we notice that the nal analogue of the magnetic force, in this particular is simply obtained from the magnetic force r^2c^2 by the replacement $e_1e_2\rightarrow -Gm_1m_2$ and, to ler in (v/c), this agrees with the result given in ref. 1. nation of equations (3) and (4), however, it is clear s not true in general.

it is now clear that arguments based on the use of ativity only[1,2] are inadequate in two major respects: ail to uncover the existence of various higher-order addition to the Gv^2 terms, the so-called gyron force[1] ch as the purely gravitational G^2 terms (which, at bound-state problems—perihelion precession of Mercury—are comparable in magnitude to the Gv^2 terms), nor the mixed Ge_ie_j terms. The existence of these nonlinear terms is intimately related to a well-known facet of general relativity theory—that the electromagnetic field and the gravitational field itself both act as sources of the gravitational field. (2) They provide no unambiguous way of deciding on the correct law of transformation of forces, whereas such a transformation emerges naturally in the general relativistic approach.

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1 Salisbury, W. W., and Menzel, D. H., *Nature*, 252, 664 (1974).
2 Lorrain, P., *Nature*, 257, 161 (1975).
3 Bazanski, S., *Acta phys. pol.*, 15, 363 (1956); *ibid.*, 16, 423 (1957).
4 Landau, L. D., and Lifshitz, E. M., *The Classical Theory of Fields*, 330 (Pergamon, Oxford, 1971).
5 Papapetrou, A., *Proc. R. Ir. Acad.*, 51, 191 (1947).
6 Majumdar, S. D., *Phys. Rev.*, 72, 390 (1947).

Dispersion and the transverse aether drag

THERE has been controversy about the correct expression of the displacement, d, introduced by the transverse motion of a dispersive dielectric slab on a light beam. Player[1] proposed the formula $d=vt(n_g-n^{-1})/c$, where v is the slab transverse velocity, t the slab thickness, n_g and n the group and wave refractive indices of the medium, respectively, and c the velocity of light in free space. This expression has been verified in very careful experiments reported by Jones[2]. I point out here that a simple model demonstrates that (in agreement with Player's formula) d must vanish when $v_gv_\varphi=c^2$, where $v_g\equiv c/n_g$ is the group velocity and $v_\varphi\equiv c/n$ is the phase velocity in the slab.

Let the slab be cut out from a set of plane parallel perfectly conducting surfaces. In other words, instead of considering a real dielectric, we consider a set of perfectly conducting sheets in air. Such artificial dielectrics are commonly used at microwave frequencies. The direction of the incident ray, the direction of the incident polarisation (E field), and the direction of the motion are assumed to be in the plane of these surfaces (see Fig. 1). The propagation of electromagnetic waves in the artificial dielectric slab just described is isotropic in the plane of the surfaces and satisfies the well known relationship $v_gv_\varphi=c^2$. On the other hand, the motion of perfectly conducting surfaces in their own plane is immaterial. Therefore the transverse displacement d of the light beam must be equal to zero when the relation $v_gv_\varphi=c^2$ holds.

The same conclusion can be reached by considering a particle with non-zero rest mass, such as an electron, traversing a set of perfectly transparent grids at different potentials[3]. As is well known, the de Broglie matter wave associated with the electron satisfies the relationship $v_gv_\varphi=c^2$, where the group velocity v_g can be identified with the electron velocity. Here

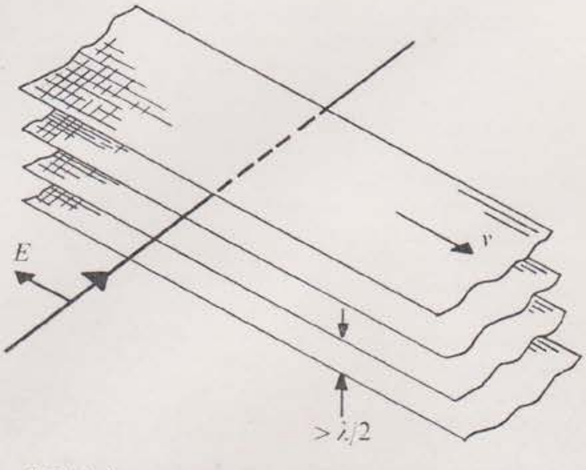

Fig. 1 Gedanken apparatus, consisting of plane parallel conducting sheets moving (velocity **v**) transverse to incident radiation.

again, it can be seen that a motion of the grids in their own plane is immaterial and should not affect the electron trajectory.

My arguments, of course, do not prove Player's formula, but they prove that alternative general formula that do not satisfy the requirement set up above are incorrect. Note that the condition $d=0$ when $v_g v_\varphi = c^2$ should hold also for light beams at non-normal incidence, a case that was not considered explicitly by Player.

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[1] Player, M. A., *Proc. R. Soc.*, A345, 343 (1975).
[2] Jones, R. V., *Proc. R. Soc.*, A345, 351 (1975).
[3] Arnaud, J. A., *Beam and Fiber Optics*, p. 41 (Academic, New York, 1976).

Tin mineralisation and mantle hot spot activity in south-eastern Missouri

SILLITOE has pointed out interesting relationships between tectonic setting and a particular class of tin mineralisation[1]. Typical mineralisation in these deposits comprises disseminated cassiterite accompanied by topaz, lithia mica, and wolframite in greisens and quartz veins above small subvolcanic alkaline and peralkaline granite plutons which lack demonstrable affiliation with contemporary plate boundaries.

I here describe briefly the tin mineralisation and petrologic–tectonic setting of the Saint Francois Mountains volcanic–plutonic terrain of south-eastern Missouri, which may possibly represent the oldest example of this class of mineral deposit.

The Saint Francois Mountains form a distinctive unmetamorphosed igneous complex comprising chiefly alkalic to peralkalic rhyolite and granite, associated with a major negative gravity anomaly[2]. The plutons seem to be more or less concordant injections into chemically-related rhyolitic ignimbrite and breccia sheets[3]. The date of this volcanic–plutonic episode is well established by recent detailed geochronologic studies[4] at about 1,500 Myr BP. The effusive rocks range in composition from andesite to rhyolite, whereas the plutonic rocks vary in composition from granodiorite to granite and minor syenite. The volcanic series and the plutonic series are each volumetrically dominated by the high-silica end members[3]. Porphyritic textures are widespread in many of the intrusive bodies; the granites locally display the well developed rapakivi texture[5] characteristic of anorogenic granites throughout the world[6]. Palaeozoic strata cover the country rock which surrounds the igneous exposures of the Saint Francois Mountains, but drill-core studies indicate the 1,500-Myr-old rocks were intruded into and erupted on an older metamorphic–plutonic terrain[7]. The exposed volcanic–plutonic complex is cut by diabase dykes and layered gabbro sills of later, but uncertain, Precambrian age[8].

The Precambrian volcanic rocks of south-eastern Missouri have long been known for their association with magmatic iron ores[9–11]. Tin mineralisation of subeconomic grade, however, is associated with the contact between rhyolite roof rocks and the intruding granite at a locality known as the Silver Mine (90.5° W; 37.5° N). The roof-zone greisen deposits of that locality have been sporadically worked for silver and tungsten during the past 100 yr. Mineralisation in the Silver Mine area consists of well-defined quartz veins containing disseminated cassiterite, lithia mica (zinnwaldite?), topaz, fluorite, wolframite (hubnerite), arsenopyrite, pyrite, chalcopyrite, sphalerite, and argentiferous galena[12]. Major, trace, and rare earth element distributions in the veins and altered wallrocks indicate extensive replacement of the host granite by high temperature, fluorine-rich solutions[13]. Original feldspars in the wallrock adjacent to the veins have been completely destroyed and supplanted by an assemblage of topaz, quartz, fluorite, sericite, lithia mica, and cassiterite[13]. Beryl and tourmaline are not present in the veins or the well defined vein envelopes of sericitic wallrock alteration[13]. This mineral assemblage and its petrologic setting are remarkably similar to those of the Younger Tin Fields of Nigeria[14] and the tin deposits of Rondônia, Brazil[15].

The tin mineralisation in south-eastern Missouri differs in major ways from the well known tin deposits of Bolivia and Japan. The latter are both located in calc-alkaline igneous settings and are thus apparently related to convergent plate processes. Sillitoe *et al.*[16] have described the Bolivian tin deposits as porphyry type mineralisation characterised by pervasive sericitic alteration, stockworks of veinlets, and widespread hydrothermal intrusion breccias—features entirely lacking in the Saint Francois Mountains deposit. The tin mineralisation of Missouri bears a resemblance to the subvolcanic (xenothermal) deposits of Japan[17] which also contain topaz and lack both tourmaline and beryl. The Japanese ores, however, contain tin minerals other than cassiterite (for instance, stannite, stannoidite, and mawsonite), primary bornite and chalcocite, native silver, and silver sulphosalts in a gangue which includes apatite, rhodochrosite, and orthoclase[17]. None of these minerals has been reported at the Silver Mine workings[13]. Lithia mica is present in Japanese hypothermal tin veins but is not found in the subvolcanic (xenothermal) deposits[17]. In the Andes of South America, subduction processes have resulted in a definite zoning of metal provinces wherein iron mineralisation and tin–molybdenum mineralisation are widely separated in space[18]. The spatial coincidence of south-eastern Missouri iron and tin mineralisation does not support the hypothesis that there is a former subduction zone beneath the Precambrian igneous terrain of the region.

The hypothesis that tin-bearing alkaline igneous complexes are generated above mantel hot spots before the formation of triple junctions and associated rifts[1] is supported by geological and geophysical relationships in south-eastern Missouri. Burke and Dewey[19] have interpreted the Mississippi Embayment as a failed arm (aulacogen) of a late Palaeozoic triple junction centred near Jackson, Mississippi, but there is evidence that this event was preceded by a major period of late Precambrian rifting in central North America which commenced about 1,300 Myr BP (refs 20–22).

Tin-bearing subvolcanic complexes in Nigeria, Rondônia, and Namibia occur in elongated belts 300–400 km long[1].