How Do Earthquakes Induce Lightenings ("More than Once!"): Piezoelectric Effect? Frictional Charging?

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Abstract

Earthquakes are known to induce lightenings often. There has been theory attributing that to piezoelectric effect in earth rocks through which the passing seismic wave may generate large electric field in rocks or soils to induce the lightenings. We study the suggested mechanism to show that that is unlikely to have sufficient magnitude and proper frequency to generate and support the observed lightenings and compare that with our suggested, different mechanism, based on frictional charging among contacting rocks.

Lightenings are electric discharges among various parts of clouds during a thunderstorm or, far less frequently, discharge from the clouds to the ground. It is known that lightenings are often observed accompanying earthquakes. [1, 2] A proposed theory [3, 4] suggests that the generated lightening is induced through piezoelectric effect [5] from the large magnitude relative pressure, mostly of random signs, in rocks or soils induced by the earthquakes. We will estimate the magnitude of this mechanism and show that that is unlikely the cause of the phenomenon. By contrast, we would propose a different mechanism, based on frictional charging. [6] We will limit our discussion to the estimation of the magnitude of the electrical field that earth quake generated by either mechanism for comparison and will not estimate the frequency of the quake taking place. We focus our discussion on earth quakes inducing lightings, not lightings inducing earthquakes which is a far less likely thus fewer observed event. Lunar quakes (quakes on the moon) have also been observed on moon which can be generated due to meteorites impact or solar wind. We note that since there is no volcano on the moon, the moon quakes can only be the results of other sources, including solar wind buildup or meteorites impact. Quakes have also been observed on various planets, the generally accepted mechanism there has mostly been attributed to uneven gravitational contraction of the planet rocks. Contrary to general claim and imagination ("Lightening does not strike twice"), lightenings *do* take place at the same place more than once. Statistically, there are $\sim 1.4 \times 10^9$ lightenings on earth each year, about 25 lightenings a second or, assuming that the quakes are uniformly placed, about three every square meter each year. [7] Historically there were belief and suggestion that it would be helpful to gather in church and ring church bell to repel thunder and strikes so the church bell had the inscription *fulgura frango* ("We chase lightenings."). People would gather under the church tower without realizing that the high church tower was the worst place to gather during a thunderstorm. Between 1775 and 1786 more than 100 were killed before the practice was stopped following the advice of Benjamin Franklin, who passed away in 1790. In comparison with lightenings, earth quakes are far less frequent. There are volcanic quakes or tectonic quakes, the latter is associated with contraction or expansion deformation of the crust of earth. (The quakes on the moon are all tectonic as there is no volcano on the moon.) Among other things, the gravitational contraction or expansion exist which could induce earth or lunar quakes. The magnitude of an earth quake is characterized by the semi-empirical Richter's scale, R, defined by: [10, 11]

$$R = (\log_{10} E - 11.8)/1.5 \tag{1}$$

where E is the released quake energy in units of ergs. We note that the number of earth quakes of magnitudes Richter's scale 5 or higher over the entire earth surface in 2024 was about 1,500 or about once every 6 hours, [9] a factor of $\sim 10^6$ fewer in comparison with the frequency of lightenings. According to Wikipedia there are roughly, on average and by estimation, 1 quake of Richter's scale 8 or higher each year, about 18 a year with Richter's scale 7 to 7.9, about 120 a year with Richter's scale 6 to 6.9, and about 1,000 to 1,500 annually with Richter's scale 5 to 5.9. In the state of Missouri it has been recorded that there are weak quakes once every week. A very strong quake observed in recent years was one in Chile on May 22, 1960 having Richter's scale 9.3 which extended over $\sim$ 500 miles from the epicenter. We estimate its total energy release to be $E_1 \sim 5.6 \times 10^{25}$ ergs (about the energy of seven hundred megaton hydrogen bombs). The deformation can be estimated at around $\delta x/x \sim 0.4$ For an earthquake of more moderate magnitude and with an assumed Richter's scale 5, its energy release can then be estimated to be at $E_2 \sim 2 \times 10^{19}$ ergs. We assume the average earth rock to have the elastic Young's modulus of the same order of magnitude and can be assumed to be at $Y \sim 10^{10} dyn/cm^2$. [12] Most quakes are below the surface of earth, at depth $\sim h \sim 80$ km $= 8 \times 10^6$ cm or lower. The earth quake at San Andreas fault in California moves roughly 2 inches a year, about the rate of toe nail growth. Given that the annual number of quakes is so much less frequent than that of lightenings ($< 10^6$), it is hard to imagine lightening to be the cause. We note that with an assumed Richter's scale 9.3, the deformation is $\delta x/x \sim 2.6 \times 10^{-3}$. We assume the average quake distortion can be modeled to be inside a column of radius r and depth h, within which the elastic distortion can be modeled to be a constant $\delta x/x$. The total elastic deformation energy can then be estimated to be $Y \pi r^2 h (\delta x/x)^2$. Setting that to U_2 the magnitude of that Chile's quake, with that much energy release and at an distance $r \sim 10$ km $\sim 10^6$ cm from the epicenter and with a depth $h \sim 8 \times 10^4$ cm, we note the magnitude of quake displacement $(\delta x/x) \sim 10^{-3}$. Most quakes have displacements far below that.

The earth soil/rock, mostly, is not a particularly strong piezoelectrical medium. We note, for example, the piezoelectrical coefficient of one solid (ZnO) with an exceptionally large piezoelectrical coefficient is about $\alpha \sim 10^{-12}$ Coulomb/Newton, [13] a unit having the dimension of electrical field per pressure. For substance with more moderate piezoelectric coefficient we consider graphite which has its piezoelectric coefficient 1.4×10^{-15} Coulomb per Newton, which earth medium typically has that on average. It is useful to note that most earth rocks are not piezoelectric medium and cannot therefore generate or support the lightenings. By contrast, friction charging exists in any rock/soil medium being rubbed and is therefore a far more likely source of lightenings. We also note that lunar quakes or quake on the moon have been observed which can only be caused by frictional force between contacting lunar rocks or soils as there are no lightenings, having no air on the moon. The seismic wave typically has longitudinal and transversal components. The longitudinal or compressional part typically has lower frequency on order of 1 to 10 Hertz and a wave velocity $v_1 \sim 5 \times 10^3 m/s$. The transversal part, shear wave, can have frequency higher, up to 100 Hertz, with wave velocity $v_2 \sim 4 \times 10^3 m/s$. From these we estimate the magnitude of electrical dipole moment a typical earth quake can generate. An electrical dipole of such an estimated magnitude on the ground and vibrating at an assumed frequency of $\omega \sim$ once very 6 hours can expect to induce an electric field high up in the thunder cloud, at an assumed height $h \sim 1000$ m, of magnitude $\sim 10^{-2}$ Coulomb per cm square.

We now estimate the needed electric field to induce lightening. For general discussions about lightenings see [1, 2, 15] A brief summary of the general properties of lightenings is as follows. If there is no cloud, there would be no lightening no matter how high an electric field, in plain air, is present. The transient nature of lightenings makes their direct measurement and study difficult. It is known that there could be X ray or γ ray lightenings associated with thunders though most lightenings are visible light or infrared. Benjamin Franklin was able to point out that what discharged in lightenings was negative. A typical thunder storm produces lightenings once every 10 to 30 seconds for a few minutes (mostly no more than 10), covering an area on order of 10 km^2. Contrary to popular mythical belief and general claim, lightenings **DO** strike twice at the same place (indeed many more times than twice): [16] the Empire State Building in New York City, *e.g.*, receives lightening strikes on average more than 20 times a year according to General Electrical Company's 10 year study. [15] We also know that Apollo 12 was struck several times while taking off. There are, on average, $\sim$ 45 lightenings per second or about one and half billion strikes a year over the entire surface of earth, most of which are intra clouds; cloud to ground strikes are far fewer frequent which, by one estimate, consist of no more than 0.1% of all the strikes. For our discussion we focus our attention on cloud to ground strikes, taking place about 1.4×10^6 a year or about 3 times a minute over the entire surface of earth. It is known that those cloud to ground lightenings transfer negative charge at the rate on order of $\sim$ 30,000 Amp. [1, 2, 15] Lightenings can be devastating: Between the years of 1950 and 1970 there were more than 1,000 deaths and more than 50,000 severe injuries in United States caused by lightenings. [17]. We note that the quake generated deformation $\delta x/x \sim (U/\pi r^2 h)^{1/2}$ and for that quake of Richter's scale 9.3 we have $\delta x/x \sim [U/(Y \pi r^2 h]^{1/2} \sim$. Thus for a strong quake of Richter's scale 9.3 we have the deformation $\alpha_1 \sim$. We note that the average earth rock/soil medium is not a particularly strong piezoelectrical medium. By one estimate, its magnitude is on average of XX from this we see that an earth quake of moderate magnitude, through piezoelectric effect, is likely to generate an electric field on order of magnitude X.

We now estimate, by comparison, what frictional charging can do. For that we need to understand frictional charging first. Discussions about friction can be found in the literature. [6] After summarizing the basic properties of frictional charging we estimate the magnitude of electric field strength induced by a typical magnitude earth quake through frictional charging to be Y. This estimates the energy release of quake, not the number of quakes itself. For the purpose of deciding which is the cause of lightnings that is all we need. Without knowing or going into detail as to the mechanism of electrical field inducing lighting we conclude, by comparing X and Y, that the electric field generated by either mechanism that the lightenings induced by earth quakes are more likely induced through frictional charging and not through piezoelectrical effect. We understand that there has been recent discussion concerning whether there are more earthquakes causing lightenings or lightenings triggering earthquakes. Our discussion is entirely based on the assumption that the lightening is caused by the quake, not lightenings inducing quakes, We compare the likely electric field generated through either mechanism, piezoelectrical effect or frictional charging, to reach our conclusion. We limit our discussion to the electric fields generated, their frequencies, and will not discuss in detail the process of electric field generating lightenings. We compare the magnitudes of electric fields generated by either mechanism, that the lightenings, in general, are random events taking place at random times and locations which do not necessarily add up constructively to generate sufficient magnitude force inducing strong lunar quakes. While not directly related to our discussion here, we note that there are lunar quakes. It is assumed that the moon has no rocks with piezoelectric properties and the lunar quakes, as detected by Apolo 16, are attributed to moon interior cooling and shrinking or through gravitational pulling and not piezoelectric effects. One may question whether likewise effects might trigger quakes on earth as well. We estimate the strengths of various mechanisms, using the results to conclude which is more likely the cause of thunderstorm.

Online access to technical literature has been rigorously forbidden to the author following his permanent disability leave and then the loss of full employment status at Washington University where he was a junior member of faculty, and his attempt to personally travel to library to read is strictly disallowed by the health care center where he has been confined at. He has, however, been

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