The Photon's Electric and Magnetic Energies Densities are Equal

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August, 2025

Abstract Planck showed that electromagnetic radiation energy is composed of photons, particles with energy $h\nu$. and that the radiation energy density is $u(\nu,T)=\dfrac{8\pi h\nu^3}{c^3}\dfrac{1}{e^{\frac{h\nu}{kT}}-1}$.

To carry electric energy, the photon ϕ has to be composed of subphotons with electric charges. To be electrically neutral, these charges must be of equal size, such as particle, and its anti-particle that will generate an electric field E_ϕ.

To carry magnetic energy, the charges have to generate magnetic field induction B_ϕ. That is, they have to constitute a current loop.

Then, the electric energy density of the photon is

$$u_{\text{electric}}=\frac{1}{2}\varepsilon_0\vec{E}_\phi^2=\frac{1}{2}u(\nu,T)=\frac{1}{2}\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1},$$

And the magnetic energy density of the photon is

$$u_{\text{magnetic}} = \frac{1}{2\mu_0}\vec{B}_\phi^2 = \frac{1}{2}u(\nu,T) = \frac{1}{2}\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}$$

Keywords: Sub-electron, Photon, Sub-photon, photon Radius, Composite Particles, electron, Radiation Energy, Electric Energy, Magnetic Energy, Centripetal Force, Electric Charge,

Physics **A**stronomy **C**lassification **S**cheme**:** 14.20-c, 14.20.Dh, 14.60Cd, 14.60.Ef, 14.60.Fg, 14.60. 14.65.-q, 14.65.Bt, 14.70.Bh, 47.32.-y, 47.32.C, 03.75., 03.75.Be, 61.05.J-, 61.05.fm,

An electron flowing through an infinitely long wire is a current I, that at distance r perpendicular to the wire, generates a Magnetic Induction field

$$\vec{B}(r) = \frac{\mu_0 I}{2\pi r},$$

along circles that lie in planes perpendicular to the wire.

If the electron races along the wire, the change of the magnetic field generates by Faraday's Law an Electric Field $\vec{E}$ perpendicular to $\vec{B}$ so that

$$\vec{\nabla} \times \vec{E} = -\partial_t \vec{B} = -\frac{\mu_0}{2\pi r}\partial_t I .$$

That Electric field generates by Ampere's Law a Magnetic field $\vec{B}_1$ perpendicular to $\vec{E}$ so that

$$\frac{1}{\mu_0}\vec{\nabla} \times \vec{B}_1 = \vec{J} + \varepsilon_0 \partial_t \vec{E} .$$

The two fields propagate in direction perpendicular to the plane of the electric and magnetic fields

The Electric Field wave equation is

$$(\partial_x^2 + \partial_y^2 + \partial_z^2)\vec{E} = \frac{1}{c^2}\partial_t^2 \vec{E}$$

The Magnetic Field wave equation is

$$(\partial_x^2 + \partial_y^2 + \partial_z^2)\vec{B} = \frac{1}{c^2}\partial_t^2 \vec{B}$$

If the electron races back and forth at frequency ν, the Electric Radiation, and the Magnetic Radiation oscillate at the same frequency ν, and propagate at the same light speed c.

The <u>Electric Radiation Energy density</u> is

$$\frac{1}{2}\varepsilon_0 \vec{E}^2 .$$

The <u>Magnetic Radiation Energy density</u> is

$$\frac{1}{2\mu_0}\vec{B}^2 .$$

The total <u>Radiation Energy density</u> is

$$u = \frac{1}{2}\varepsilon_0 \vec{E}^2 + \frac{1}{2\mu_0}\vec{B}^2$$

In 1902, Planck established that the radiation energy is composed of packets of energy of size

$$h\nu ,$$

where

$$h = \text{Planck Constant}$$

was determined by Planck.

The radiation energy density satisfies Planck Radiation Law

$$u(\nu, T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}} - 1}.$$

Later, those particles were called photons.

To carry electric energy, the photon has to have an electric field E_ϕ, and be composed of subphotons with electric charges. To be electrically neutral, these charges must be of equal size, such as particle, and its anti-particle.

To carry magnetic energy, the charges have to generate a magnetic field induction B_ϕ. That is, they have to constitute a current loop.

It follows that a photon ϕ may be composed of a particle, and its anti-particle at distance $2r_\phi$, chasing each other in a circular motion, so that the centripetal force keeps them from falling on each other.

The particles are likely a sub-electron, and its antiparticle.

The magnetic field of a subphoton at the other at diameter distance $2r_\phi$ is

$$\vec{B}_\phi = \frac{\mu_0}{4\pi}\frac{\frac{1}{3}\mathrm{e}}{(2r_\phi)^2}v_\phi = \frac{\mu_0}{4\pi}\frac{\frac{1}{3}\mathrm{e}}{(2r_\phi)^2}c$$

Then, the <u>magnetic energy density due to the subphoton</u> is

$$\frac{1}{2\mu_0}B_\phi^2 = \frac{1}{2\mu_0}\left(\frac{\mu_0}{4\pi}\frac{\frac{1}{3}\mathrm{e}}{(2r_\phi)^2}c\right)^2.$$

The electric field of sub-photon with charge of $\frac{1}{3}e$ is

$$\vec{E}_{\phi} = \frac{1}{4\pi\varepsilon_0}\frac{\frac{1}{3}\mathrm{e}}{(2r_{\phi})^2}$$

The <u>electric energy density due to the subphoton</u> at the other subphoton at diameter distance $2r_{\phi}$ is

$$\frac{1}{2}\varepsilon_0 E_{\phi}^2 = \frac{1}{2}\varepsilon_0\left(\frac{1}{4\pi\varepsilon_0}\frac{\frac{1}{3}\mathrm{e}}{(2r_{\phi})^2}\right)^2$$

Then,

$$\frac{u_{\text{magnetic}}}{u_{\text{electric}}} = \frac{\frac{1}{2\mu_0}\left(\frac{\mu_0}{4\pi}\frac{\frac{1}{3}\mathrm{e}}{(2r_{\phi})^2}c\right)^2}{\frac{1}{2}\varepsilon_0\left(\frac{1}{4\pi\varepsilon_0}\frac{\frac{1}{3}\mathrm{e}}{(2r_{\phi})^2}\right)^2} = 1$$

$$u_{\text{electric}} = \frac{1}{2}\varepsilon_0\vec{E}_{\phi}^2 = \frac{1}{2}\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}$$

$$u_{\text{magnetic}} = \frac{1}{2\mu_0}\vec{B}_{\phi}^2 = \frac{1}{2}\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}$$

For visible light at midrange frequency, $\nu = 6\times 10^{14}\,\text{cyc/sec}$.

At room temperature, $T = 300\text{K}$.

$$\frac{h\nu}{kT} \sim \frac{(6.26\cdot 10^{-34})(6\cdot 10^{14})}{(1.38)10^{-23}300} \sim 91$$

The radiation energy density is

$$u(\nu, T) = \frac{8\pi}{c^3} h\nu^3 \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

$$\approx \frac{8\pi}{c^3} h\nu^3 \frac{1}{e^{\frac{h\nu}{kT}}}$$

$$\sim \frac{8\pi}{(3\cdot 10)^8}(6.26)10^{-34}(6\cdot 10^{14})^3 \frac{1}{e^{91}}$$

$$\sim \frac{8\pi}{3^3 10^{24}}(6.26)10^{-34} 6^3 10^{42} \frac{1}{(3.3)10^{39}}$$

$$\sim (1.3)10^{-52}\text{Joul/m}^3$$

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