`Einstein's Wave-Particle Fallacy: Radiation Is NOT a Mixture of Photons and Waves

H. Vic Dannon
vic0@comcast.net
August, 2018

Abstract: In papers, and in meetings in 1909, Einstein made the bizarre claim that Planck's Radiation Law implies that Electromagnetic Radiation is a mixture of waves , and photons.

He followed his Brownian motion derivation, to derive a formula for the Radiation Pressure.

His derivation is not convincing, and the formula is not credible.

But he never applied it to prove his claim.

Instead, he repeatedly used Planck Radiation Law, the consequence of quantum assumptions, to express the radiation energy as a sum of a term that includes photons, and another that includes photons too, but must be wavy.

We show that radiation is NOT a mixture of photons and waves.

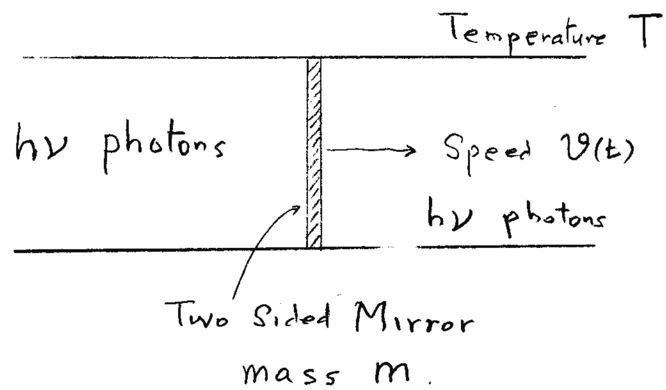
Keywords: Planck's Radiation law, Electromagnetic Radiation, Thermal Radiation, Black-Body Radiation, Brownian Motion, Wave Theory, Photon, Quantum, Radiation Pressure, Radiation Reaction, Momentum Transfer,

Physics & Astronomy Classification Scheme: 42.50.Pq, 42.50.Lc,

1.

Einstein's Radiation Pressure

[Einstein1], presents a setup in which Radiation Pressure will appear.



Electromagnetic Radiation at frequency between

$$\nu, \quad \text{and} \quad \nu + d\nu$$

fills a cylinder at absolute temperature

$$T.$$

A double sided Mirror of mass

$$m,$$

placed as a piston in the cylinder, moves without friction at time t with speed

$$v(t).$$

The speed $v(t)$ is a random variable. Hence it may point in either direction, and its time average is zero.

The Radiation generates a Frictional $\dfrac{\text{Force}}{v(t)}$

$$P,$$

which units are

$$\frac{\text{Newton}}{\text{meter/sec}}.$$

This frictional force/speed decreases the mirror's speed by

$$dv_{\text{friction}} = a_{\text{friction}}dt.$$

Substituting this in

$$ma_{\text{friction}} = Pv(t),$$

$$m\frac{dv_{\text{friction}}}{dt} = Pv(t),$$

$$dv_{\text{friction}}(t) = \frac{Pv(t)dt}{m}.$$

Therefore,

$$v(t+dt) = v(t) + dv - dv_{\text{friction}},$$

$$= v(t) + dv - \frac{Pv(t)dt}{m}.$$

Einstein Assumed that

the time average of $v^2(t)$ equals the time average of $v^2(t+dt)$.

That is,

$$E\left[\left(\upsilon(t)+d\upsilon-\frac{P\upsilon(t)dt}{m}\right)^2\right]=E\left[\left(\upsilon(t)\right)^2\right],$$

$$E\left[\upsilon^2(t)+(d\upsilon)^2+\left(\frac{P\upsilon(t)dt}{m}\right)^2+2\upsilon(t)d\upsilon-2\frac{P\upsilon^2(t)dt}{m}-2d\upsilon\frac{P\upsilon(t)dt}{m}\right]$$

$$=E[\upsilon^2(t)],$$

$$E\left[(d\upsilon)^2+\left(\frac{P\upsilon(t)dt}{m}\right)^2+2\upsilon(t)d\upsilon-2\upsilon(t)\frac{P\upsilon(t)dt}{m}-2d\upsilon\frac{P\upsilon(t)dt}{m}\right]=0.$$

Ignoring second order infinitesimals such as

$$(d\upsilon)^2,\ (dt)^2,\ d\upsilon dt,$$

we end up with

$$E\left[\upsilon(t)d\upsilon-\frac{P\upsilon^2(t)dt}{m}\right]=0,$$

$$E[\upsilon(t)d\upsilon]=E[\upsilon^2(t)]\frac{P}{m}dt.$$

Einstein assumed that the average speed is zero, and claimed, [Einstein1, p.368]

"*the average value of* $\upsilon(t)d\upsilon$ *obviously vanishes*".

Then, we have

$$0=E[\upsilon^2(t)]\frac{P}{m}dt.$$

Since $m\neq 0$, $dt\neq 0$, and $E[\upsilon^2(t)]\neq 0$, we must have

$$P = 0,$$

and No Radiation Pressure.

That is, Null result.

To avoid that, Einstein denoted dv by a capital letter,

$$dv = \Delta.$$

That notation hidden the fact that dv is an infinitesimal, and its square is negligible with respect to dt.

Hence, Einstein did not have to drop $(dv)^2 = \Delta^2$ and he got

$$\Delta^2 = 2E[v^2]\frac{P}{m}dt.$$

Consequently,

$$P \neq 0.$$

And there in no Null result, and Einstein could apply the last formula to prove that Radiation is a mixture of photons and waves.

Except that he never applied it.

The formula turned out to be just a diversion.

It infers nothing regarding the composition of Radiation.

Einstein never established his bizarre claim that Radiation is a mixture of photons and waves.

2.

Einstein's Claim that Radiation Is a Mixture of Waves and Photons

[Einstein1,p.368], states that

"by *a calculation omitted here for the sake of brevity*",...,

$$P = \frac{3}{2c}\left[\rho - \frac{1}{3}\nu\frac{d\rho}{d\nu}\right]A_{rea}d\nu\,,$$

where

P is the Radiation Pressure,

ρ is the radiation energy density in $[\nu, \nu + d\nu]$

Einstein advised to plug ρ from Planck's Radiation Law, stated in [Einstein1, p.370]

$$\rho = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}} - 1}.$$

Hence,

$$\frac{d\rho}{d\nu} = 3\frac{8\pi h\nu^2}{c^3}\frac{1}{e^{\frac{h\nu}{kT}} - 1} + \frac{8\pi h\nu^3}{c^3}\frac{-1}{(e^{\frac{h\nu}{kT}} - 1)^2}e^{\frac{h\nu}{kT}}\frac{h}{kT}$$

$$\frac{1}{3}\nu\frac{d\rho}{d\nu}=\underbrace{\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}}_{\rho}-\frac{1}{3}\frac{1}{kT}h\nu\underbrace{\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}}_{\rho}\left(\underbrace{\frac{e^{\frac{h\nu}{kT}}-1}{e^{\frac{h\nu}{kT}}-1}}_{1}+\frac{1}{e^{\frac{h\nu}{kT}}-1}\right)$$

$$\rho-\frac{1}{3}\nu\frac{d\rho}{d\nu}=\underbrace{\rho-\rho}_{0}+\frac{1}{3}\frac{1}{kT}h\nu\rho\left(1+\frac{1}{e^{\frac{h\nu}{kT}}-1}\right)$$

$$=\frac{1}{3}\frac{1}{kT}h\nu\rho+\frac{1}{3}\frac{1}{kT}\rho h\nu\underbrace{\frac{1}{e^{\frac{h\nu}{kT}}-1}}_{\frac{\rho c^3}{8\pi h\nu^3}}$$

$$=\frac{1}{3}\frac{1}{kT}\left(h\nu\rho+\frac{\rho^2c^3}{8\pi\nu^2}\right)$$

Therefore,

$$P=\frac{3}{2c}\left[\rho-\frac{1}{3}\nu\frac{d\rho}{d\nu}\right]A_{rea}d\nu\,,$$

$$=\frac{\cancel{3}}{2c}\left[\frac{1}{\cancel{3}}\frac{1}{kT}\left(h\nu\rho+\frac{\rho^2c^3}{8\pi\nu^2}\right)\right]A_{rea}d\nu$$

By [Einstein1, p. 369], the average of the squared energy fluctuation, ε^2 in the volume V_{olume} in the frequency interval $[\nu,\nu+d\nu]$ is

$$E[\varepsilon^2]=\left(h\nu\rho+\frac{\rho^2c^3}{8\pi\nu^2}\right)V_{\text{olume}}d\nu\,.$$

Einstein claims that

$h\nu\rho$ is due to Radiation of Photons,

while

$\dfrac{\rho^2 c^3}{8\pi\nu^2}$ is due to Radiation of Waves.

[Einstein2, p.393] says about the wave term

> *"According to the wave theory, beams of not very different directions, not very different frequencies, and not very different states of polarization must interfere with each other, and to the totality of these interferences, which occur in the most random fashion there must correspond a fluctuation of the radiation pressure.*
>
> *That the expression for this fluctuation must have the form of the second term of our formula can be seen by a simple dimensional analysis.*
>
> *One can see that the wave structure of radiation indeed causes the fluctuations of radiation pressure to be expected from it."*

[Einstein2, p.393] says about the photon term

> *"For*
>
> $\lambda = 0.5\mu$, *and* $T = 1700$,

this term is about

$$6.5 \cdot 10^7$$

times larger than the second one.

If radiation consisted of very small sized complexes of energy

$$h\nu$$

moving through space independently of each other, and reflected independently of each other,...,

then the momenta acting on our plate due to fluctuations of the radiation pressure, would be of the kind represented by the first term alone."

In [Einstein2, p.394] Einstein Concludes

"...the wave structure, and the quantum structure simultaneously displayed by radiation according to the Planck formula should not be considered as mutually incompatible."

3.

Radiation Is NOT a Mixture of Waves and Photons

Clearly, the expression

$$\rho - \frac{1}{3}\nu\frac{d\rho}{d\nu}$$

does not indicate a wave portion, and a photon portion.

That is why Einstein prefers the expression that follows from it

$$h\nu\rho + \frac{\rho^2 c^3}{8\pi\nu^2}.$$

3.1

But in which way does

$h\nu\rho$ become solely due to Radiation of Photons,

while

$\frac{\rho^2 c^3}{8\pi\nu^2}$ is solely due to Radiation of Waves.

What is so particle-like about the first term, and so wavy about the second?

Both terms depend on ρ. That is, on photon radiation alone.

Both depend on the photon energy $h\nu$.

And $h\nu$ appears four times in the second term. Recall that

$$\frac{\rho^2 c^3}{8\pi\nu^2} = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}h\nu\frac{1}{e^{\frac{h\nu}{kT}}-1}.$$

3.2

According to Einstein, the key to the difference is

"simple dimensional analysis"

> *"That the expression for this fluctuation must have the form of the second term of our formula can be seen by a simple dimensional analysis."*

Whatever that means, if it was so simple, why was it so complicated for Einstein to supply it?

3.3

We don't know what made Einstein think that repeated application of Planck's Radiation law

$$\rho = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1},$$

the consequence of the quantum assumption, will reveal a wavy portion in Radiation.

References

[Einstein1] A. Einstein, "*On the Present Status of the Radiation Problem*", The Collected Works of Albert Einstein, Volume 2, Document 56, pp. 357-375, 1909, Princeton University Press, 1989

[Einstein2] A. Einstein, "*On the Development of our Views Considering the Nature and Constitution of Radiation*", The Collected Works of Albert Einstein, Volume 2, Document 60, pp. 379-394, 1909, Princeton University Press, 1989