Light Crossing a Box Carries a Weight E/c^2, and the Emitter's Rest Mass Falls by More, by the Recoil

— the condition that the centre of mass does not move fixes the light's weight at E/c^2 regardless of flight time or rigidity, and the emitter's rest mass reaches 0 at $E = Mc^2/2$ — the separator is whether the weights are rest masses or energies — [Paper 911]

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— From thinking to syncing. —

Abstract

With something massless like light, it is hard to see where the weight is carried in mass-energy equivalence.Using the thought experiment of sending light from one end of a closed box to the other, this paper counts the weight carried by the light from the single condition that the centre of mass does not move, and counts exactly in relativity how much the rest masses of the emitter and absorber change.No new theorem or law is claimed. First, the weight carried by the light is E/c^2 regardless of the flight time——in a rigid box with $c = 1$, $M = 1$, $L = 1$ and $E = 0.1$, the flight time shrinks to 0.909090909 because the box moves toward the light, yet the weight obtained from the box's shift of $9.090909091 \times 10^{-2}$ and the distance travelled by the light matched E within 10^{-12} (Section 2). **Second, a rigid box need not be assumed——in a chain of 50 masses joined by springs, with speeds of sound 0.01, 0.1 and 0.5, the final shifts of the left end differ, -1.062687×10^{-2}, -1.025273×10^{-3} and -1.265673×10^{-4}, but the centre of the chain shifted in every case by $\mathbf{-1.000000000 \times 10^{-4}}$ ($= -EL/(Mc^2)$)** (Section 2). **Third, varying the weight placed on the light, the centre of mass stays put only at E/c^2——with weights 0, 0.5, 1 and 2 times that, the shift of the centre of the whole system was $-1.000000000 \times 10^{-4}$, $-5.000000000 \times 10^{-5}$, $-4.449294665 \times 10^{-17}$ and $+1.000000000 \times 10^{-4}$** (Section 3). **Fourth, and this is the core. The emitter's rest mass falls by more than E/c^2, by the kinetic energy of its recoil——with $c = 1$ and an emitter and absorber of mass 1, at $E = 0.1$ the emitter's rest mass falls by $\mathbf{0.105572809}$ (1.055728 times E) and the absorber's rises by 0.095445115, and the differences matched the kinetic energies of the two recoils within 10^{-12}. At $E = 0.5$ the emitter's rest mass reaches 0, a fall of 2.000000 times E** (Section 4). **Fifth, the centre weighted by energy does not move, while the centre weighted by rest mass does——the former stayed at 0.500000000000 for five values of E and five times. The latter jumps at the moment of emission (0.500250250 at $E = 0.001$), moves at a speed of $-0.500250E$ while the light flies, jumps again on absorption, and afterwards moves at a speed proportional to E^4 ($\mathbf{1.000003}$ when divided by E^4)** (Section 4). **Sixth, the separator is whether the weights are rest masses or energies——in the model of 1 kg, 1 m and 1 J, the box's shift of 1.112650×10^{-17} m and the light's weight of 1.112650×10^{-17} kg are the same number, and the kinetic energy of the recoil is only 5.563250×10^{-18} of E. The difference between the two ways of weighting hides inside this smallness** (Sections 5 and 6). **Keywords**: Einstein's box, mass-energy equivalence, centre of mass, momentum of light, recoil, rest mass.

Scope of this paper (scope note): **No new theorem or law is claimed——the argument deriving E/c^2 from the centre of mass of a box of light (Einstein's box; Einstein 1906), the idea of assigning to radiation a fluid of mass E/c^2 to save the motion of the centre of mass (Poincaré 1900), that a body whose energy falls by E loses mass E/c^2 (Einstein 1905), that in relativity the centre weighted by energy moves at constant velocity, and the formula for the emitter's loss of rest mass are all known.The momentum of light in media is not entered——the light flies in vacuum, and the debate over the momentum of light in media (Abraham and Minkowski) is not entered.Light is not counted as photons——the light is a classical pulse, and quantum treatment is not entered.No experiment is claimed——1 kg, 1 m and 1 J are model values, and actually measuring the box's shift is not entered.The chain model is kept to one——the springs are linear, the speed they transmit is slower than light, and a relativistic treatment of springs is not entered.Relation to earlier papers**: **Paper 12 read $E = mc^2$ in the form of the surface area of a sphere——here the same c^2 is counted from the centre of mass of a box, as the denominator of the weight carried by light.Paper 908 counted that in the field of a charged spherical shell the mass counted by momentum is $4/3$ times the mass counted by energy——the light here, flying free of the walls, carries momentum E/c, and the weights counted by momentum and by energy agree at the same E/c^2.Paper 240 showed that "mass" is seven things——here, whether the weights are rest masses or energies decides whether the centre of mass moves.Paper 664 counted that the recoil was not removed but taken by the crystal ——here the box takes the recoil, and its shift measures the weight of the light. The kinetic energy of the recoil enters the emitter's loss of rest mass.Paper 83 showed that relativity with a maximum speed follows from Galileo's relativity principle alone——here that maximum speed c enters the light's momentum E/c and weight E/c^2.**What is added is **showing that the weight in a rigid box does not depend on the flight time**, **measuring the shift of the centre from the positions of a chain that assumes no rigidity**, **counting the changes in the rest masses of emitter and absorber separated into the kinetic energies of recoil**, **setting the centre weighted by energy beside the centre weighted by rest mass and showing that the latter jumps and moves at first and fourth order**, and **placing the separator on rest mass versus energy**.

1. Notation and the Question

Setting: **a box of mass M and length L is at rest. When the left wall emits light of energy E to the right, the box receives momentum E/c and moves left, stopping when the light reaches the right wall. Counted as a rigid box, this gives the following.**

$$v = \frac{E}{Mc}, \qquad t = \frac{L}{c+v}, \qquad Mvt = mct \quad \Longrightarrow \quad m = \frac{Mv}{c} = \frac{E}{c^2}$$

The m here is the weight that must be placed on the light for the centre of mass not to move, and the flight time t cancels on both sides.To count exactly in relativity, with $c = 1$, an emitter of mass M_A and an absorber of mass M_B are placed at rest. With energy and momentum conserved, the rest masses after emission and after absorption, and the centre weighted by energy, are as follows.

$$M_A' = \sqrt{M_A^2 - 2M_A E}, \qquad M_B' = \sqrt{M_B^2 + 2M_B E}, \qquad X_E = \frac{\sum_i E_i\, x_i}{\sum_i E_i}$$

In the model that assumes no rigidity, a chain of 50 masses joined by springs was given momentum $-E/c$ at its left end and $+E/c$ at its right end when the light arrived, moved to time 3 by the velocity Verlet method (step 10^{-4}), and the shift of the chain's centre was measured from the positions of the masses.

Question: **when light is sent inside a box, what weight must be placed on the light for the centre of mass not to move, and how much do the rest masses of emitter and absorber then change?**

2. A Rigid Box and a Chain of Springs

Computation 2.1: **a rigid box with $c = 1$, $M = 1$, $L = 1$.**

E	flight time of light	shift of box	weight from the centre-of-mass condition
0.001	0.999000999	$9.990009990 \times 10^{-4}$	$1.000000000 \times 10^{-3}$
0.01	0.990099010	$9.900990099 \times 10^{-3}$	$1.000000000 \times 10^{-2}$
0.1	0.909090909	$9.090909091 \times 10^{-2}$	$1.000000000 \times 10^{-1}$

Computation 2.2: **a chain joined by springs ($E = 10^{-4}$).**

speed of sound	shift of right end when light arrives	final shift of left end	shift of chain's centre	final total momentum
0.01	-2.328×10^{-189}	-1.062687×10^{-2}	$-1.000000000 \times 10^{-4}$	-7.589×10^{-19}
0.1	-1.848×10^{-91}	-1.025273×10^{-3}	$-1.000000000 \times 10^{-4}$	-2.191×10^{-19}
0.5	-1.832×10^{-25}	-1.265673×10^{-4}	$-1.000000000 \times 10^{-4}$	1.382×10^{-18}

Observation 2.3

the weight carried by the light is E/c^2 regardless of the flight time, and a rigid box need not be assumed.In the rigid box, even when the flight time shrank to 0.909090909 at $E = 0.1$, the box's shift and the distance travelled by the light shrank in the same proportion, and the weight stayed E——in the chain, the right end had not yet moved when the light arrived (shifts from -2.328×10^{-189} to -1.832×10^{-25}), and the final shift of the left end differs by a factor of 83.962236 between speeds of sound 0.01 and 0.5. Still, the shift of the chain's centre was $-1.000000000 \times 10^{-4}$ in all three cases: internal forces do not move the centre, so the shift is fixed by the momentum E/c and the flight time L/c alone.

3. The Weight Placed on the Light

Computation 3.1: **for the chain with speed of sound 0.1, the weight w placed on the light was varied and the shift of the centre of the system of chain and light was obtained. When the light arrives, the weight w moves from the emitter to the absorber.**

w	shift of the system's centre
0	$-1.000000000 \times 10^{-4}$
$0.5E/c^2$	$-5.000000000 \times 10^{-5}$
E/c^2	$-4.449294665 \times 10^{-17}$
$2E/c^2$	$+1.000000000 \times 10^{-4}$

Observation 3.2

the centre of mass stays put only when a weight E/c^2 is placed on the light.With no weight on the light, a closed box would have shifted by $EL/(Mc^2)$ without receiving anything from outside——doubling the weight shifts it by the same amount in the opposite direction. The shift of $-4.449294665 \times 10^{-17}$ at E/c^2 is 4.449×10^{-13} times that with weight 0, and smaller than 1.110×10^{-16}, the rough size of rounding when the centre's position 0.5 is counted in double precision.

4. Counting Exactly in Relativity

Computation 4.1: with $c = 1$, emitter $M_A = 1$ at $x = 0$ and absorber $M_B = 1$ at $x = 1$. The ratios are values divided by E.

E	emitter's fall (ratio)	absorber's rise (ratio)	emitter's recoil	absorber's recoil	fall of total rest mass
0.001	0.001000501 (1.000501)	0.000999500 (0.999500)	0.000000501	0.000000500	0.000001000
0.01	0.010050506 (1.005051)	0.009950494 (0.995049)	0.000050506	0.000049506	0.000100013
0.1	0.105572809 (1.055728)	0.095445115 (0.954451)	0.005572809	0.004554885	0.010127694
0.3	0.367544468 (1.225148)	0.264911064 (0.883037)	0.067544468	0.035088936	0.102633404
0.5	1.000000000 (2.000000)	0.414213562 (0.828427)	0.500000000	0.085786438	0.585786438

Computation 4.2: the centre weighted by rest mass (the rest mass of light is 0, so the light carries no weight).

E	just after emission	just before absorption	just after absorption minus just before emission	speed while flying$/E$	speed after absorption$/E^4$
0.001	0.500250250	0.499750000	5.005×10^{-10}	-0.500250	1.000003
0.01	0.502525317	0.497500320	5.052×10^{-7}	-0.502500	1.000300
0.1	0.527864045	0.475404494	5.670×10^{-4}	-0.524596	1.030823

Observation 4.3

this is the core. The emitter's rest mass falls by more than E/c^2, by the kinetic energy of its recoil.The weight of the light is exactly E/c^2, but the emitter pays from its rest mass not only the light but also the kinetic energy of its own recoil, so at $E = 0.1$ the fall is 1.055728 times E. The absorber turns part of the light's energy into recoil, so its rise stays at 0.954451 times——the fall of the total rest mass, 0.010127694, matched the sum of the kinetic energies of the two recoils. At $E = 0.5$ the emitter's rest mass reaches 0 and it moves at speed -1.000000, the same speed as light.

Observation 4.4

the centre weighted by energy does not move, while the centre weighted by rest mass does.With the light's energy placed at the light's position, the centre weighted by energy stayed at 0.500000000000 for five values of E at times from 0 to 10——the centre weighted by rest mass jumps at emission as the emitter's weight falls, moves at a speed close to $-E/2$ while flying because it leaves behind the weightless light, and jumps again on absorption. Its speed after absorption is proportional to E^4: at $E = 0.001$ it is 1.000003 times E^4.

5. Model Values

Computation 5.1: $M = 1$ kg, $L = 1$ m, $E = 1$ J, $c = 299792458$ m/s.

quantity	value
momentum of light E/c	3.335641×10^{-9} kg m/s
speed of box $E/(Mc)$	3.335641×10^{-9} m/s
flight time of light	3.335641×10^{-9} s
shift of box	1.112650×10^{-17} m
weight carried by light E/c^2	1.112650×10^{-17} kg
kinetic energy of recoil $E^2/(2Mc^2)$	5.563250×10^{-18} J

Observation 5.2

for a box of 1 kg and 1 m, the box's shift in metres and the light's weight in kilograms are the same number.As the chain showed, the box's shift is mL/M——the kinetic energy of the recoil is 5.563250×10^{-18} of E, and the difference between weighting by rest mass and by energy hides inside this size.

6. The Separator

Observation 6.1

the separator is whether the weights are rest masses or energies.Weighting by energy, the light also carries weight, and the centre does not move at emission, in flight or after absorption——weighting by rest mass, the light's weight is 0 and the centre jumps and moves; only when the light's weight is set to E/c^2 does the first-order shift vanish.

Observation 6.2

placed among the earlier papers.The c^2 of $E = mc^2$, which Paper 12 read in the form of the surface area of a sphere, came out here from the centre of mass of a box as the denominator of the weight carried by light——in the charged shell of Paper 908, the masses counted by momentum and by energy differed by $4/3$, but for light flying free of the walls they agree. Among the seven masses of Paper 240, weighting by rest mass or by energy splits the motion of the centre, and the recoil of Paper 664 entered here into the fall of rest mass. The maximum speed c of Paper 83 enters the light's momentum and weight.

Observation 6.3

what is not said.The momentum of light in media, treatment as photons, actual measurement of the box's shift, a relativistic treatment of springs, and the convention of the one-way speed of light are not treated——what is shown is that, for a classical pulse of light flying in vacuum, the condition that the centre of mass does not move fixes the weight of the light at E/c^2, and the emitter's rest mass falls by more than that, by the kinetic energy of its recoil.

7. Census and Closing

1. $Mvt = mct$ (Section 1): **the flight time cancels.**
2. **flight time** 0.909090909 **at** $E = 0.1$ (Computation 2.1): **the weight stays** E**.**
3. **shift of chain's centre** $-1.000000000 \times 10^{-4}$ (Computation 2.2): **the same for three speeds of sound.**
4. $-1.000000000 \times 10^{-4}$ **with weight** 0 (Computation 3.1): **the centre moves.**
5. **emitter's fall** 0.105572809 (Computation 4.1): 1.055728 **times** E**; the core.**
6. **absorber's rise** 0.095445115 (Computation 4.1): **the differences are the kinetic energies of recoil.**
7. **fall of** 2.000000 **times at** $E = 0.5$ (Computation 4.1): **the emitter's rest mass reaches** 0**.**
8. **energy-weighted centre** 0.500000000000 (Observation 4.4): **does not move.**
9. **speed of rest-mass-weighted centre**$/E^4$ 1.000003 (Computation 4.2): **jumps and moves.**
10. **rest mass, or energy** (Observation 6.1): **the separator; Papers 12, 908, 240, 664, 83.**

Closing: **When light is sent across a box, the centre of mass stays put only if the light carries a weight** E/c^2**, and the emitter's rest mass falls by more than that, by the recoil.In a rigid box and in a chain of springs alike, the weight of the light from the centre-of-mass condition is** E/c^2 **regardless of flight time or speed of sound, and the chain's centre shifted by the same** $-1.000000000 \times 10^{-4}$ **for three speeds of sound——setting the light's weight to** 0 **or twice that made the centre move.Counted exactly in relativity, at** $E = 0.1$ **the emitter's rest mass fell by** 0.105572809 **and the absorber's rose by** 0.095445115**, the differences being the kinetic energies of the two recoils. The centre weighted by energy stayed at** 0.500000000000**, while the centre weighted by rest mass jumped and moved——the weight of light is exactly** E/c^2**, and the change of rest mass has the recoil mixed in.Placed among the earlier papers——the** c^2 **of Paper 12 came out of a box's centre of mass as the denominator of the light's weight, and the recoil of Paper 664 entered the fall of rest mass.To be honest——this is a computation for a classical pulse of light in vacuum, and does not enter the momentum of light in media, photons, or actual measurement.**

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