Essay on E equals m c squared

OKD/Physical Sciences/Physics/Relativity/E equals m c squared

Particle energy varies directly with mass and light-speed squared {E equals m c squared}: $E = m * c^2$.

gravity and electromagnetism

Gravitation energy relates to electromagnetism energy.

Both electromagnetic force and gravitational force exchange zero-rest-mass particles, so both forces have effects out to infinite distances.

Electromagnetism and gravitation are spatial fields. Electromagnetism makes radial electromagnetic-field lines. Gravity makes radial gravitational-field surfaces. Surfaces have more space than lines, so electromagnetism is stronger than gravity.

Electromagnetic and gravitational waves do not travel through a medium. They propagate by induction along field lines and surfaces. Wave-propagation speed depends on field strength and field type. Electromagnetism is stronger than gravity, but in same proportion gravity uses more space, making both field lines and surfaces have maximum tension, so both electromagnetic and gravitational waves travel at light speed.

energy

Object total energy equals rest energy plus kinetic energy plus potential energy: $E = RE + KE + PE$. Kinetic energy varies directly with mass and velocity squared: $KE = 0.5 * m * v^2$. Potential-energy change PE varies directly with local force-field force and position change d in field: $PE = F * d$. Rest energy is constant.

energy and momentum

In classical physics, particle energy and momentum are separate physical properties, with separate conservation laws. Energy conservation depends on time symmetry. Momentum conservation depends on space symmetry.

In relativity, space and time unite in four-dimensional space-time. By experiment and calculation, all particles and objects travel at light speed through space-time. Particle motion through space-time has momentum and energy, but energy is through time and momentum is through space. In space-time, momentum and energy unite into one four-dimensional vector {energy-momentum four-vector} (4-momentum). Energy is time-like component, and momentum is space-like component.

energy and momentum conservation

For constant particle rest energy, energy conservation means that potential-energy change equals negative of kinetic-energy change. In space-time, potential energy changes through space, and kinetic energy changes through time. Kinetic-energy change changes velocity and so changes momentum. Because energy and momentum stay constant, energy-momentum four-vector separation is invariant for any inertial space-time reference frame and under any linear coordinate transformations. For potential energy (including rest energy) and momentum changes, 4-momentum-vector space-time separation has equation, in space units: $s^2 = E^2 / c^2 - p^2$, where E is change in potential energy and rest energy, and p is kinetic-energy change in space units. (Dividing by c makes time units into space units.)

rest-mass energy

Resting masses {proper mass} (rest mass) have no speed through space dimensions, and so travel through time dimension at light speed c. Along time dimension, rest-mass 4-momentum-vector separation s is m0 * c, where m0 is rest mass. Because rest masses do not change space position, potential energy is zero, and rest mass is constant. Because rest masses have no velocity, kinetic energy is zero, and momentum is zero. Therefore, s^2 = (m0 * c)^2 = E^2/c^2 - (0)^2, so E = m0 * c^2.

Rest mass has available energy. Rest masses are like energy concentrations. Mass densities are like energy fields.

moving masses

Moving masses have increased positive kinetic energy. Increased kinetic energy is similar to concentrated mass, so stationary observers calculate that moving masses have mass increase (relativistic mass).

Moving mass goes through space-time separation m * c, where m is total mass (rest mass and relativistic mass). Moving mass has momentum total-mass times velocity. Rest-mass energy is rest mass times light speed. For example, if potential energy is zero (with no gravity), and velocity is 0.75 * c, - s^2 = - (m * c)^2 = - (m0 * c^2)^2/c^2 - (m * 0.75 * c)^2, then - m^2 * c^2 = - m0^2 *c^2 - (0.75)^2 * m^2 * c^2, and then - 0.25 * m^2 = - m0^2, and total mass m = 2 * m0.

In empty space, energy E depends on rest energy, in time dimension, and kinetic energy KE, in space dimensions. Rest energy = m0 * c^2. KE depends on momentum p: KE = p * c. Total energy sums rest energy and kinetic energy {relativistic energy-momentum equation}: E^2 = (m0 * c^2)^2 + (p * c)^2.

For zero-rest-mass particles, E = p*c.

For resting masses, p = 0, and E = m0 * c^2.

For moving masses, total energy is total mass m times light-speed squared: E = m * c^2. If velocity is near zero, total mass is almost the same as rest mass. If velocity is near light speed, total mass is very large, much greater than rest mass.

relativistic mass increase

Objects traveling through space have momentum and kinetic energy. Higher-velocity objects travel more through space and less through time, causing more time dilation and length contraction. Objects traveling more through space increase 4-momentum momentum and kinetic energy, in the same proportion that time dilates. Therefore, total mass m increases with velocity: m = m0 / (1 - (v^2 / c^2))^0.5, where c is light speed, v is velocity, and m0 is rest mass. For example, if velocity is 0.75 light speed, total observed mass is twice rest mass.

equivalence

Energy in time dimension can go into momentum in space dimensions, and vice versa {mass-energy equivalence}.

relativistic energy in series format

In series format, in empty space, total energy E = m0 * c^2 + m0 * v^2 / 2 + (3 * m0 * v^4) / (8 * c^2) + ..., where m0 is rest mass. See Figure 1. The first term is the rest energy. The sum of the higher-power terms is the kinetic energy. For slow particles, later terms are very small, so kinetic energy is m0 * v^2 / 2, matching the classical value of 0.5 * m * v^2.

mass and energy equivalence

Particle decomposition and composition experiments show that mass and energy are equivalent and depend only on reference frame.

cases

An unstable particle with mass can become two zero-rest-mass particles that travel at light speed in opposite directions from particle position. Zero-rest-mass particles have no potential energy. Moving particles have kinetic energy. Mass changes into kinetic energy, to conserve mass-energy. Momentum in one direction equals momentum in opposite direction, to conserve momentum.

An unstable particle with mass can become two particles, one with mass and one with no mass. Total mass is less than before, to conserve energy. The zero-rest-mass particle travels at light speed in opposite direction from new particle with mass, which travels at less than light speed. Momentum in one direction equals momentum in opposite direction, to conserve momentum.

Two particles with mass can collide to make one particle with mass and one zero-rest-mass particle. The zero-rest-mass particle travels at light speed in opposite direction from new particle with mass, which travels at less than light speed, to conserve energy. Momentum in one direction equals momentum in opposite direction, to conserve momentum.

Two equal particles can collide and stop, so kinetic energy becomes mass. Total mass is then more than sum of rest masses before.

Figure 1

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E = PE      + KE
E = m0*c^2                  + m0*(v^2)/2    + 3*m0*(v^4)/8*c^2  + ...
E = m0*(c^2 + c0*(v^2)^0 + c1*(v^2)^1  + c2*(v^2)^2        + c3*(v^2)^3 + ...)
E = m0*(c^2 + 0             + (0.5)*(v^2)^1 +  (3/8*c^2)*(v^2)^2 + ...)
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