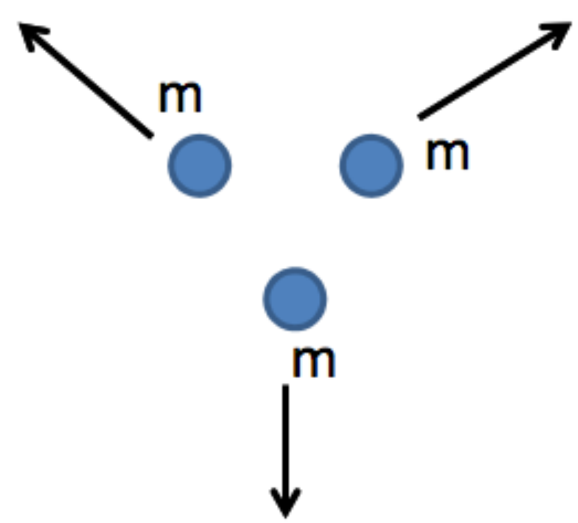
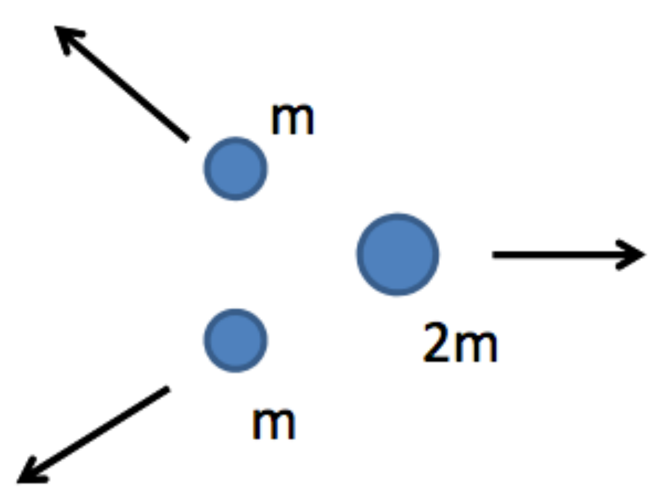
An unstable particle of mass 3m decays into lighter particles. Which of the following represents a possible final state?

A)

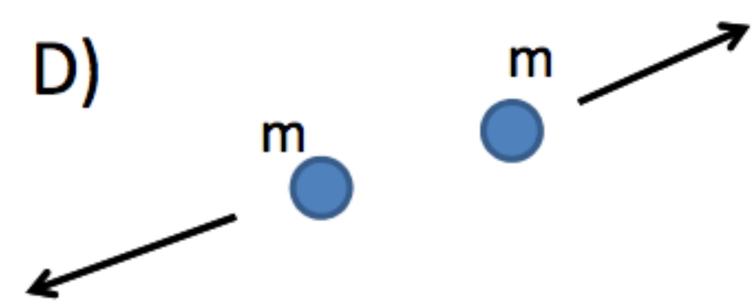


B)

C)



D)



E) Both A and B

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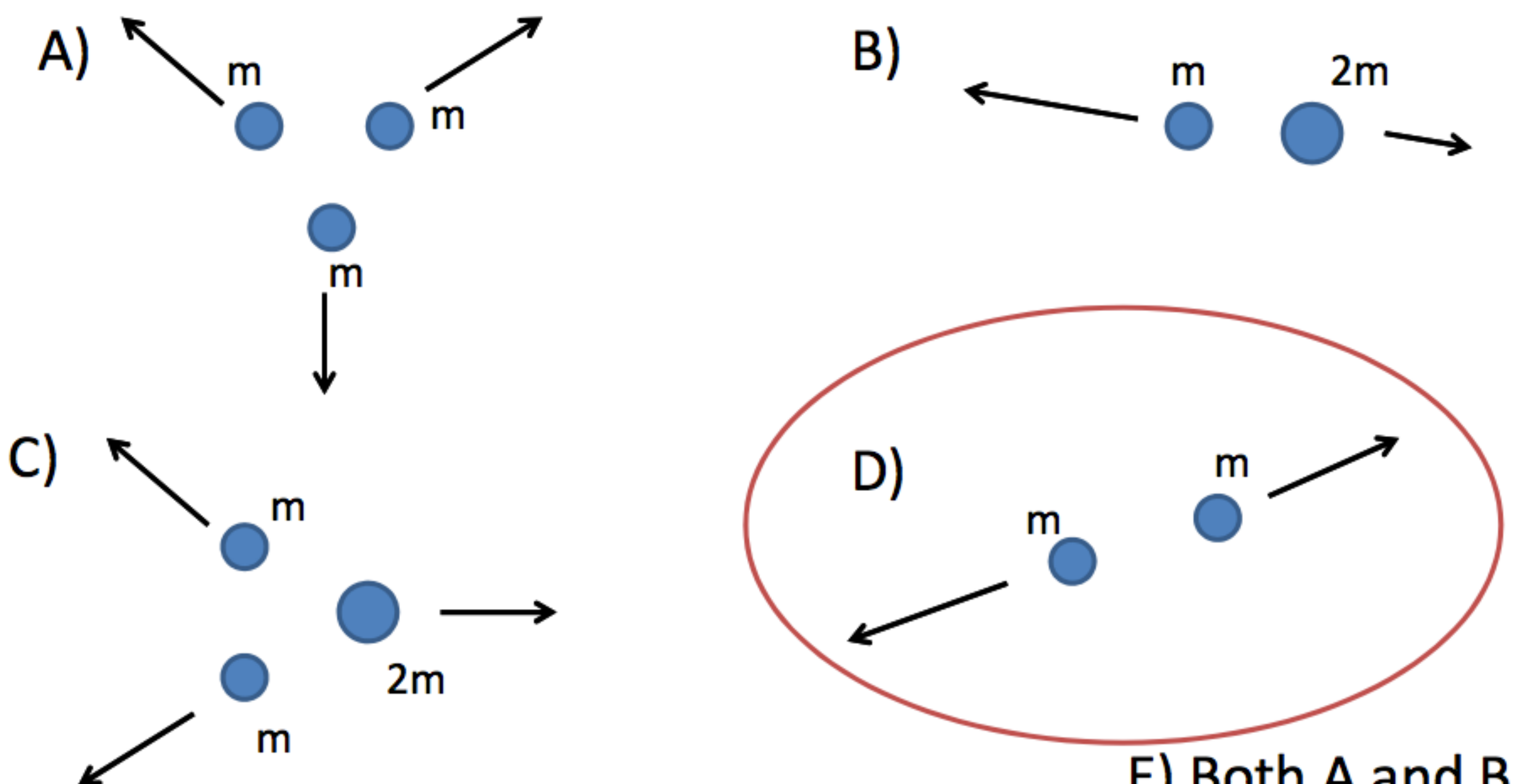


E) Both A and B

The initial energy is $3mc^2$. The energy of A, B, and C is more than $3mc^2$.

Relativistic Energy

For small velocities:

1) Mass is always conserved
2) kinetic energy only conserved in elastic collisions.

In relativity:

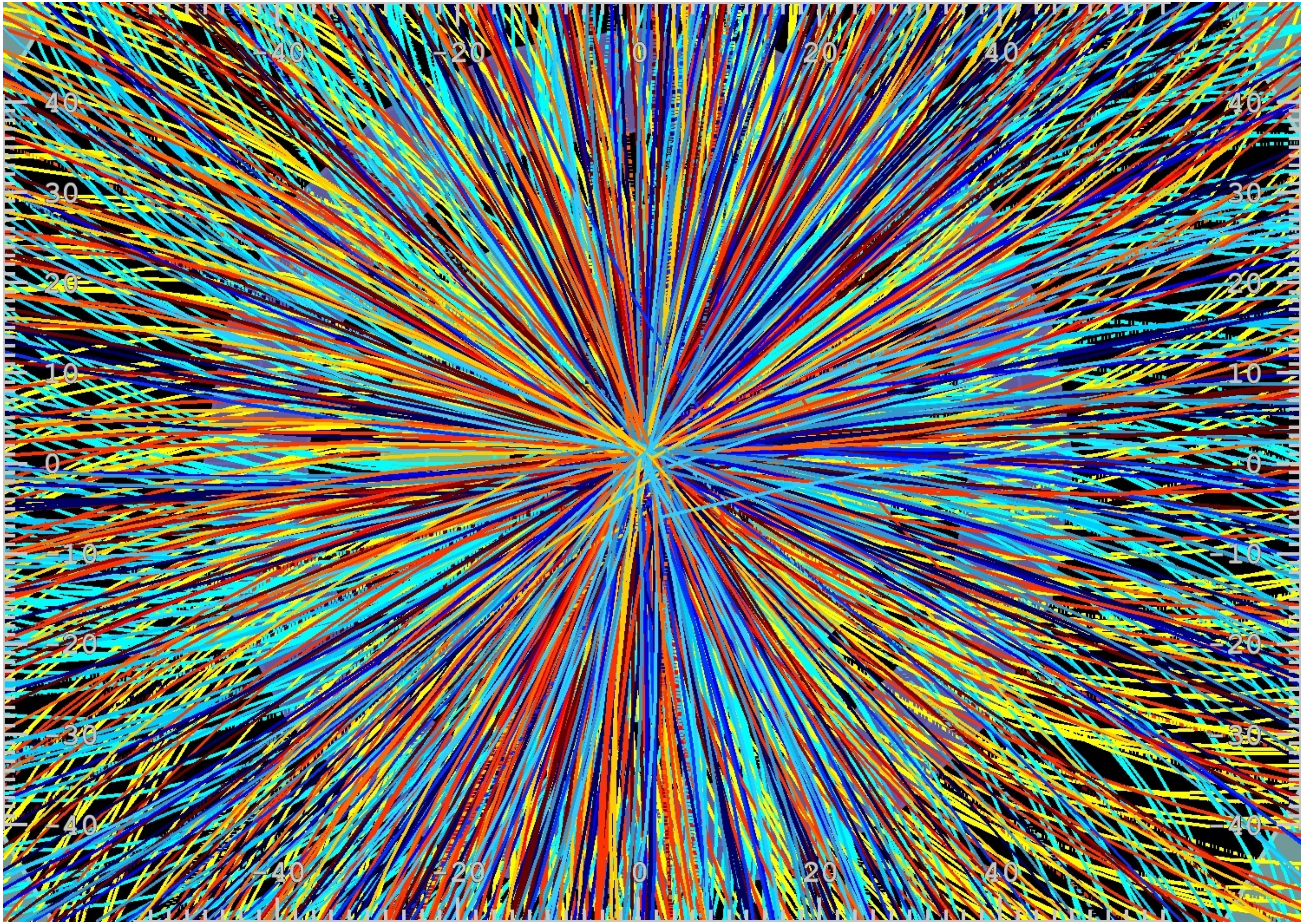
$$E = mc^2 + (\gamma - 1)mc^2$$

mass energy

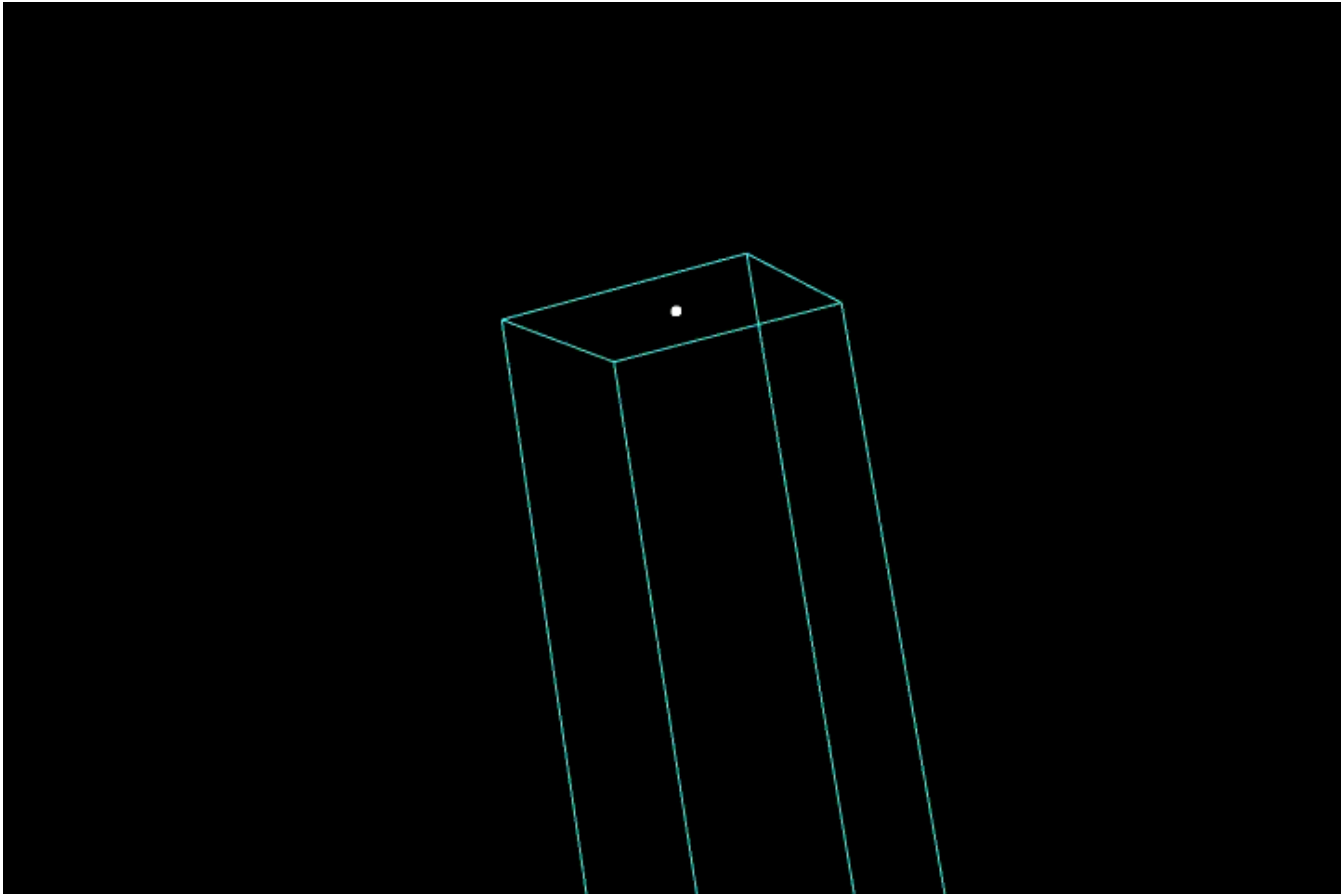
relativistic kinetic energy

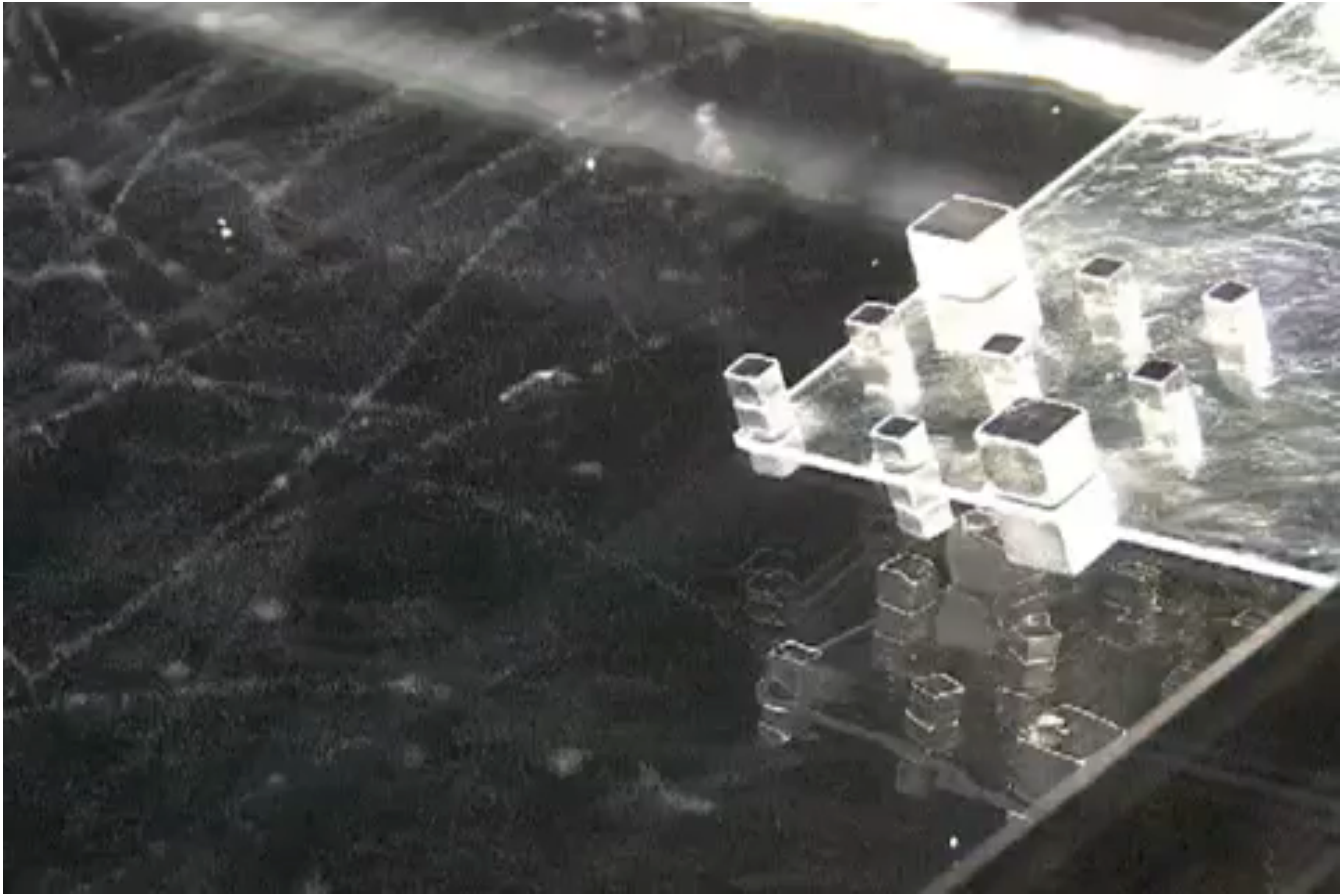
1) The combination of these two is conserved in all processes.
2) Mass isn’t conserved, but we can convert mass to kinetic energy and back again.

Particle Physics



Cosmic Rays

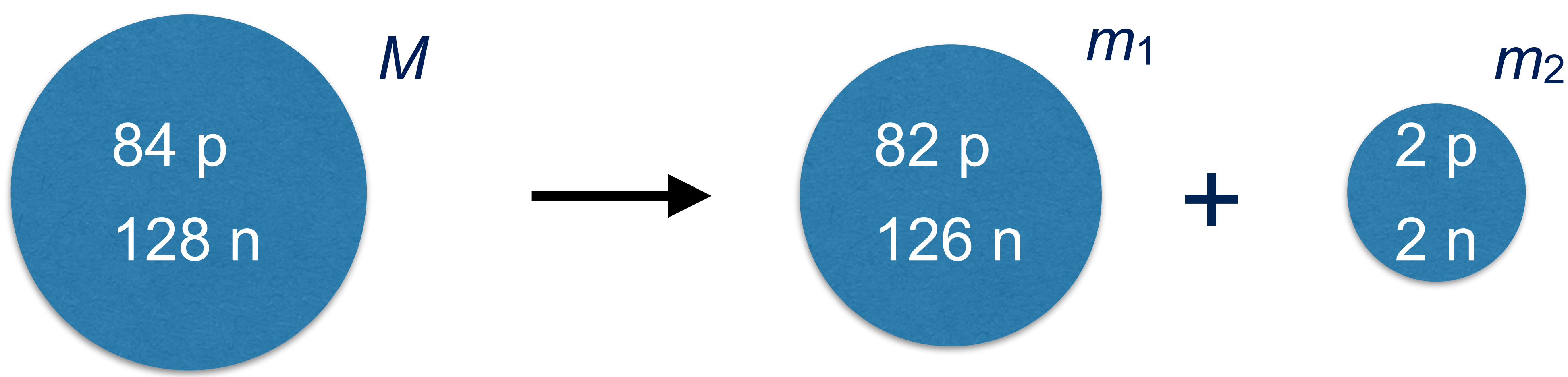




Nuclear Power (Fission)

Energy is created when heavy elements decay into lighter ones.

$$^{212}\mathrm{Po} \rightarrow {}^{208}\mathrm{Pb} + \alpha$$



$$M > m_2 + m_2$$

The energy released is equal to $(\Delta M)c^2 = 1.4 \times 10^{-12}$ J which goes into kinetic energy that essentially heats water. It’s an enormous amount of energy when multiplied by Avogadro’s number

Q: What is Mass?

When the object is a rest we see that

$$E = mc^2$$

We can use this as another definition of mass (as opposed to shooting peas at space salmon)

A: Mass = (total energy of an object at rest) x $1/c^2$

A stationary space salmon has a mass of 20 kg. In the frame of reference of an observer moving at v=3/5c relative to the space salmon, the mass of the salmon is:

A) 16kg
B) 20kg
C) 25kg
D) Cannot be determined

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A) 16kg
B) 20kg
C) 25kg
D) Cannot be determined

Mass is equal to the energy of an object when it is not moving, divided by c^2. So in the new frame of reference, the kinetic energy and total energy are larger, but the mass is still 20kg.

Two balls of pure gold at rest each contain exactly 10^{23} gold atoms. One ball is at room temperature, while the other ball is at 1000K. Which ball is more massive?

A) The cooler ball
B) The hotter ball
C) They have the same mass

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A) The cooler ball
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C) They have the same mass

Same atoms, but more kinetic energy, so total energy is greater. Mass is the total energy of an object at rest divided by c^2.

How does the mass of a hydrogen atom compare to the mass of a proton plus the mass of an electron?

A) It is the same: $m_H = m_p + m_e$

B) It is less: $m_H < m_p + m_e$

C) It is greater: $m_H > m_p + m_e$

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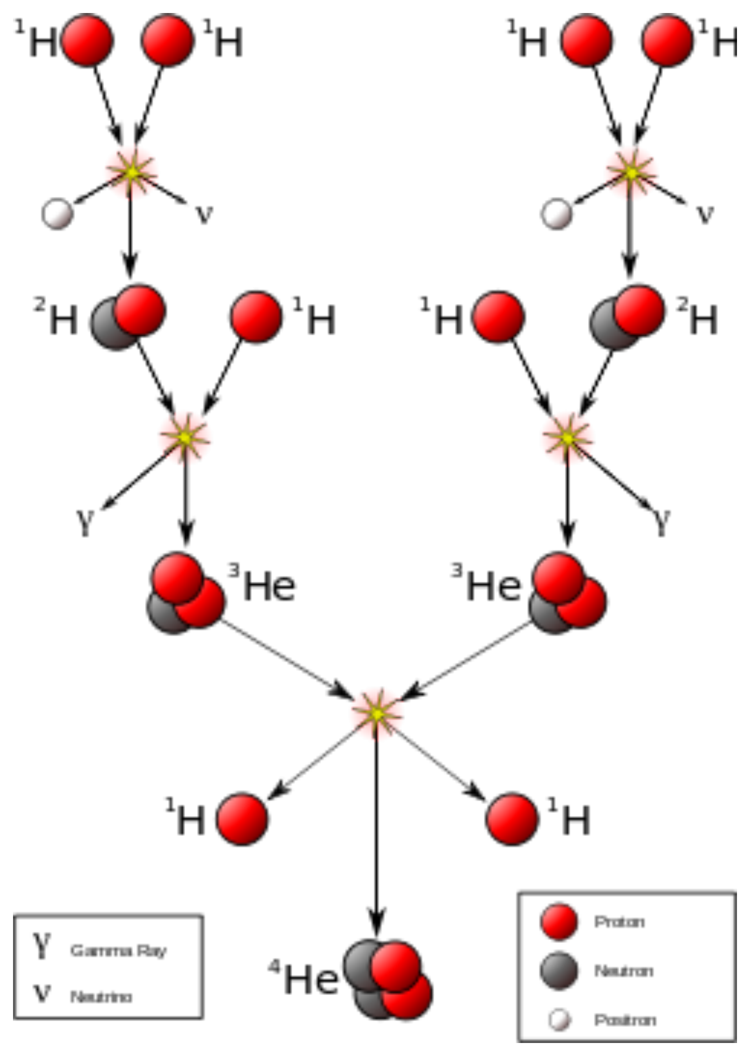
Need to add energy to separate into proton and electron, so energy conservation tells us:

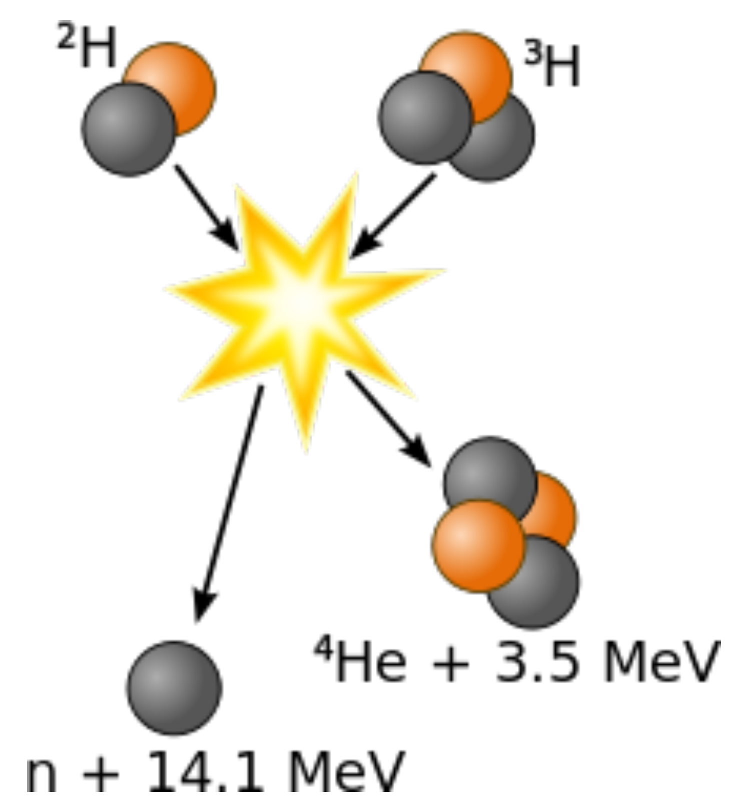
$m_H c^2 + \text{energy} = m_p c^2 + m_e c^2$

This means $m_H < m_p + m_e$

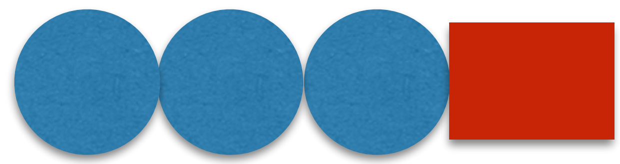
Nuclear Power (Fusion)

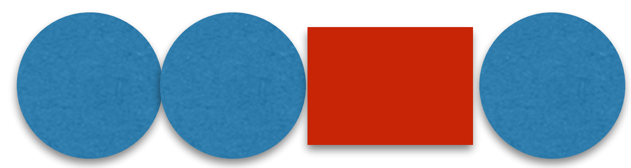
Energy is created when two light elements are forced very close together.





Which configuration of steel balls and magnets has the lower mass?

A) 

B) 

C) Impossible to tell.

D) They have the same mass.

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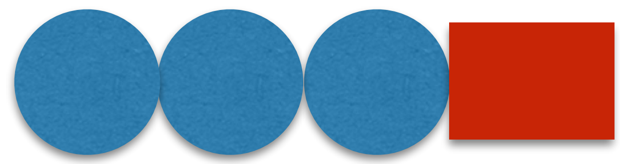
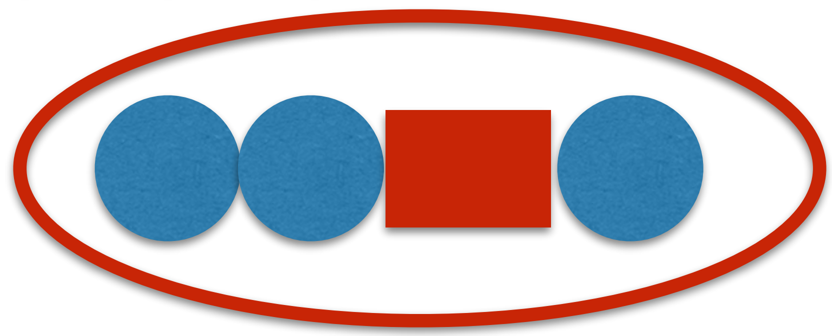
A) 

B) 

C) Impossible to tell.

D) They have the same mass.

Configuration B is more tightly bound. It's harder to pull the right ball from B than it is to pull the left ball from A. This means that B has a lower overall potential energy, and thus has a lower mass.

$$M = 3\, m_{\text{ball}} + m_{\text{mag}} + (\text{thermal energy})/c^2 + (\text{potential energy})/c^2$$

potential energy is more *negative* for more tightly bound state.

Q: What is Mass?

Generally,

$$\text{Mass} = \text{constituent particle masses} + \frac{\text{particle kinetic energies}}{c^2} + \frac{\text{potential energy}}{c^2}$$

Binding energy: this is negative for stable systems, so stable systems have less mass.

This definition agrees with previous definitions of inertial mass and gravitational mass.

Previous Definitions

Using momentum:

Mass = amount of impulse to change *v* by a certain amount

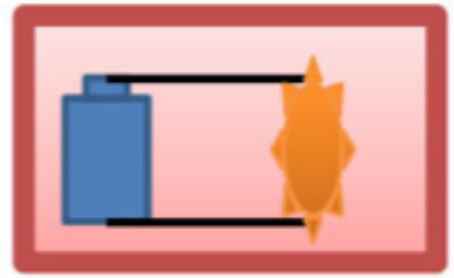
This is called "inertial mass".

Usually:

$$\text{Mass} = \frac{\text{an object's weight}}{\text{g (it's free fall acceleration)}}$$

This is called "gravitational mass"

All three agree!

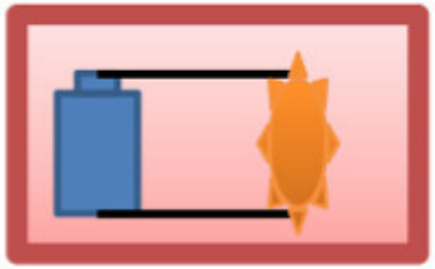


Suppose we build a sealed box which contains a battery connected to a heater which gradually heats the air inside the box. Assuming the box is completely isolated, and that the box neither absorbs nor emits any particles or radiation, what happens to the mass of the box (including its contents) as time passes?

A) The mass increases.

B) The mass decreases.

C) The mass stays the same.



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A) The mass increases.
B) The mass decreases.
C) The mass stays the same.

Mass is the total energy of the object (box and its contents) in its rest frame. For this isolated system total energy is conserved, so the mass stays the same no matter what happens inside the box.