

This is pages 6 - 7. It is practice problems and a continuation of the regents level information

# Matter Waves



- ◆ A photon's momentum can be represented by the following equation

$$p = \frac{h}{\lambda}$$

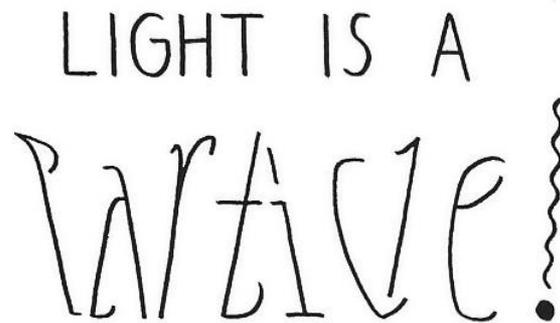
Reminder – de Broglie figured out the momentum of a photon

\* Not on Reference Table

# Matter Waves

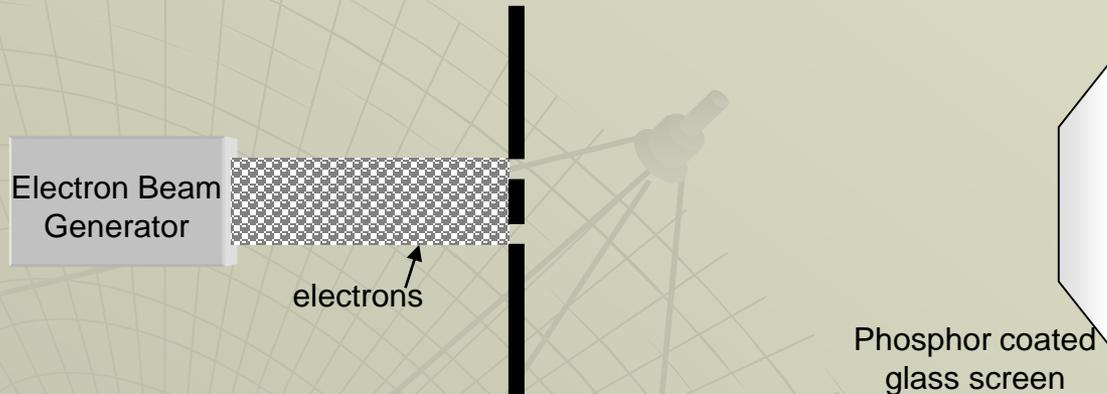
- ◆ In 1923 DeBroglie suggested that if a wave behaves like a particle . . .
- ◆ then a particle could behave like a wave

Then proposed something crazy. Until Einstein got involved.

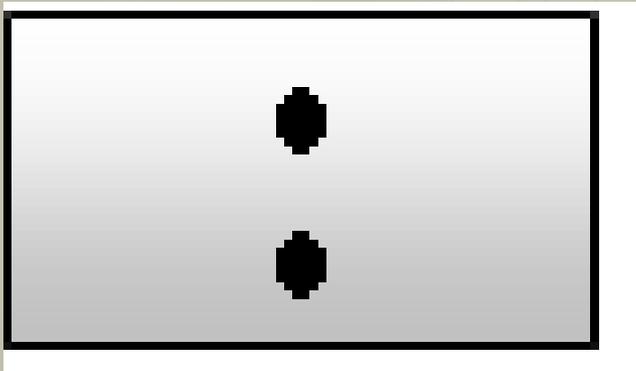
A white rectangular box containing the text "LIGHT IS A WAVE!". The words "LIGHT IS A" are in a simple, uppercase, sans-serif font. The word "WAVE!" is written in a large, cursive, handwritten style with a wavy line for the letter 'V' and a solid dot for the period.

- ◆ What wave phenomenon could test this?

# Matter Waves

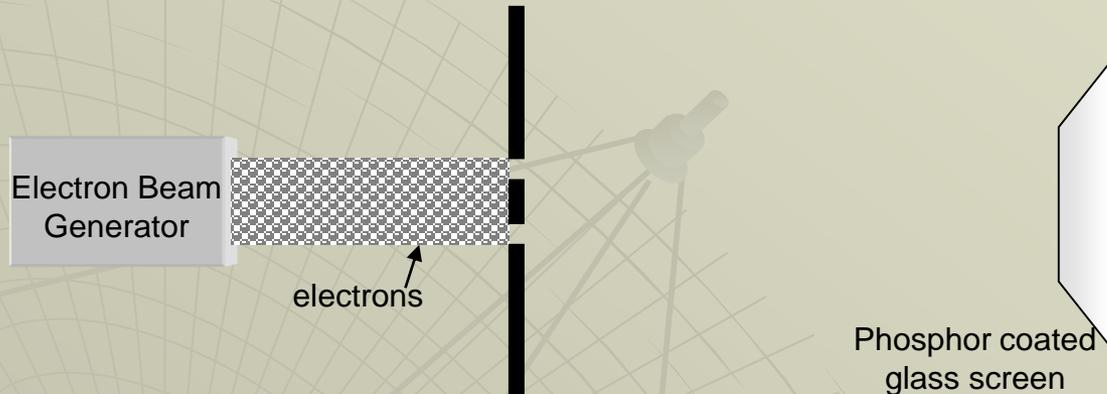


- ◆ If electrons acted **just like particles**, what would you expect to see on the screen?

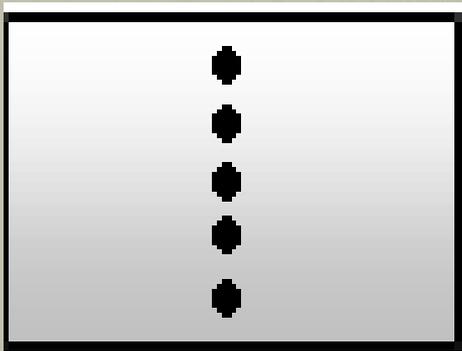


You would only see two bright dots, because only electrons at the opening could pass.

# Matter Waves

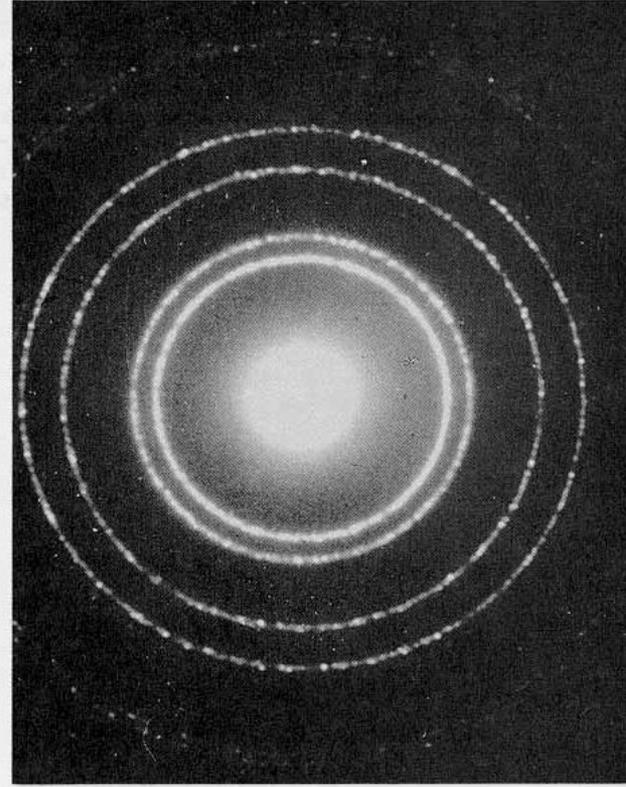
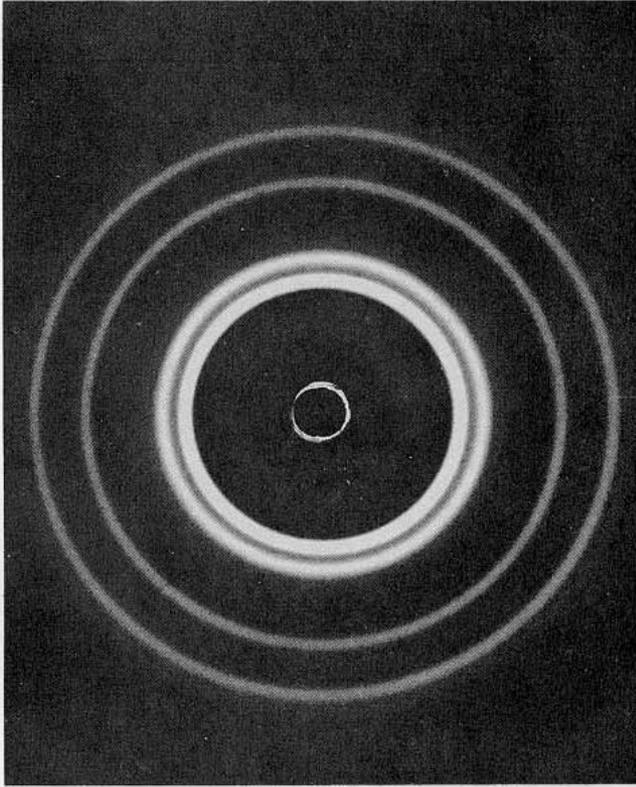


- ◆ What pattern **was seen** on the screen? What did it indicate about electrons?



A typical interference pattern was seen. It shows that the electrons behaved similar to waves

The diffraction pattern on the left was made by a beam of x rays passing through thin aluminum foil. The diffraction pattern on the right was made by a beam of electrons passing through the same foil.



X-ray interference pattern on the left, electron interference pattern on the right. Almost the same.

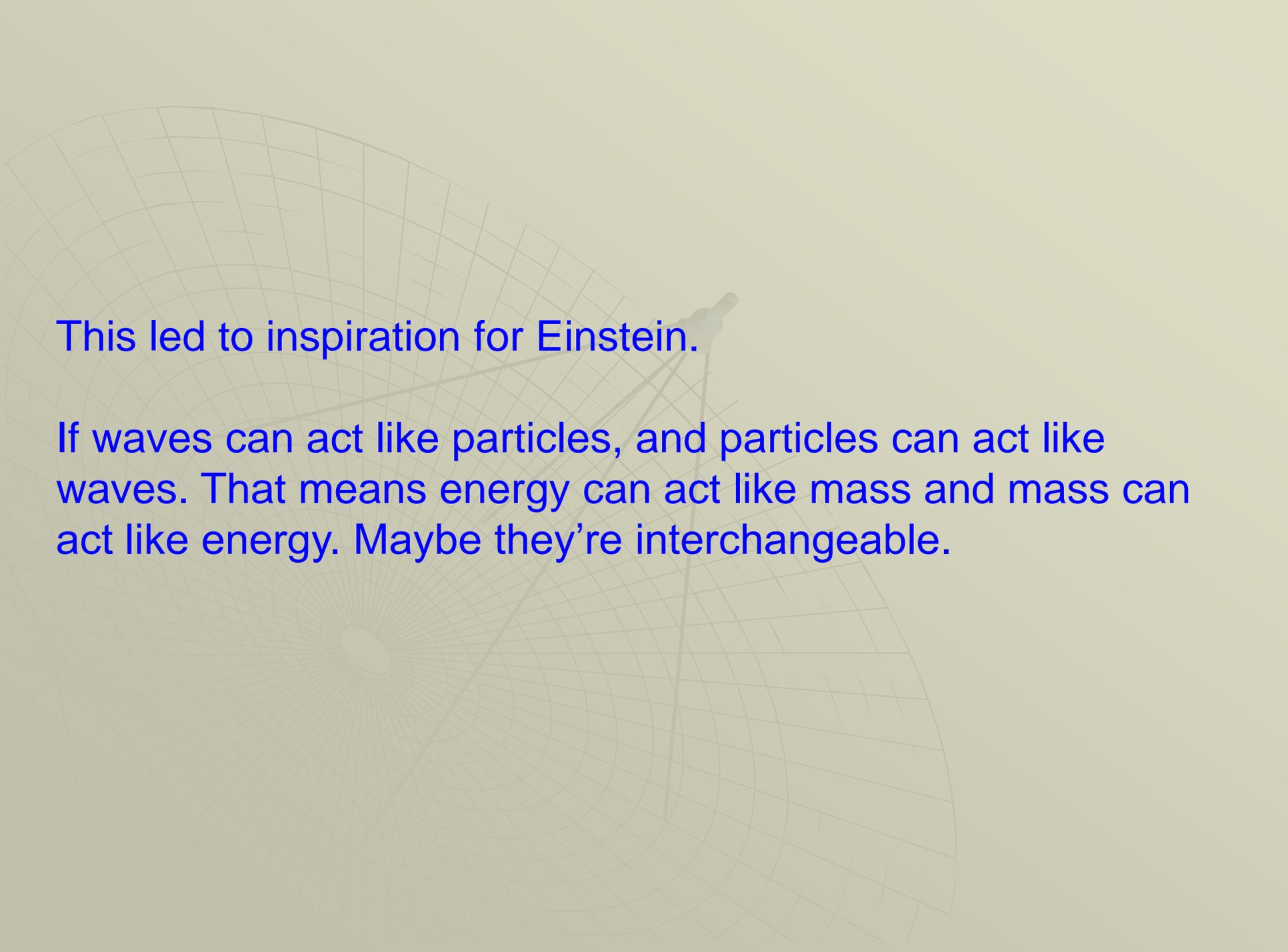
# Matter Waves

- ◆ The dual nature of matter:

Matter in motion exhibits particle as well as wave characteristics.

(The wavelengths of ordinary objects, like a thrown baseball, are too small to be detected.)

- ◆ As the speed of an electron increases, its wavelength **decreases**

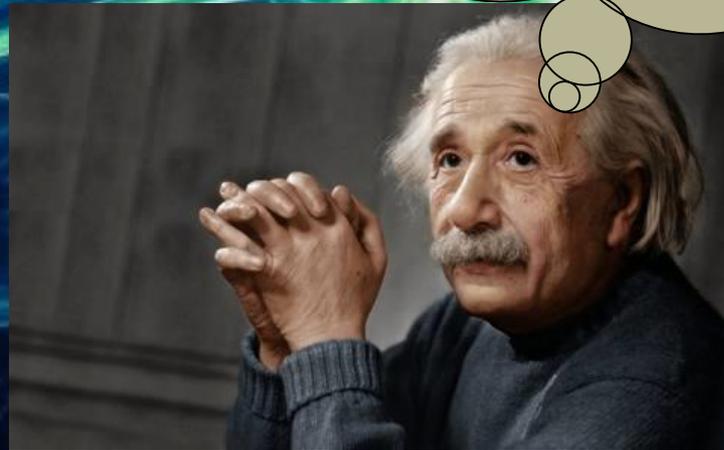


This led to inspiration for Einstein.

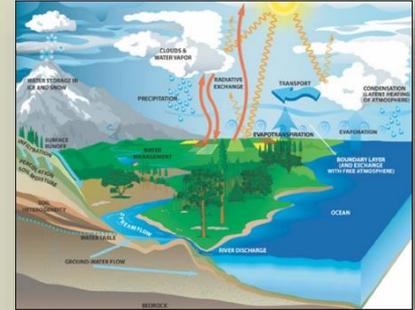
If waves can act like particles, and particles can act like waves. That means energy can act like mass and mass can act like energy. Maybe they're interchangeable.

$$E = mc^2$$

If light (energy) can act as a particle (matter) and electrons (matter) can act as a wave (energy).

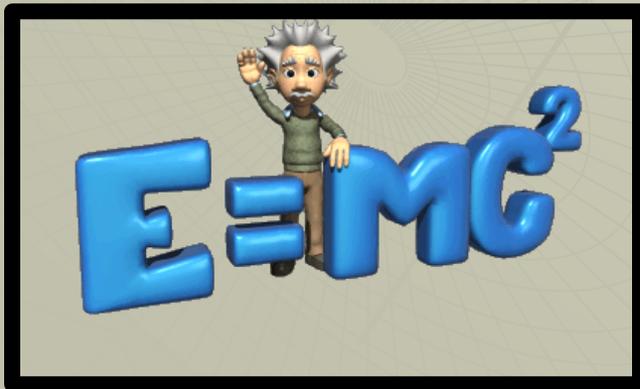


# Mass-Energy Relationship



According to Albert Einstein:

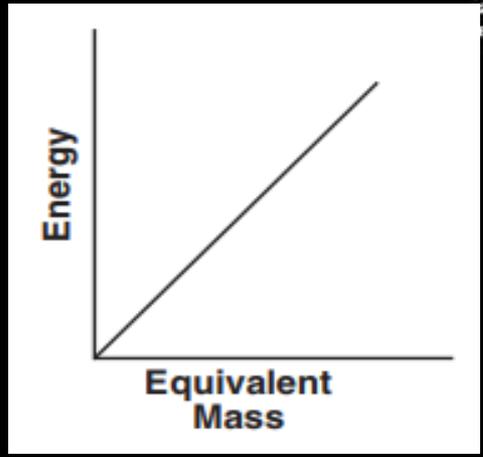
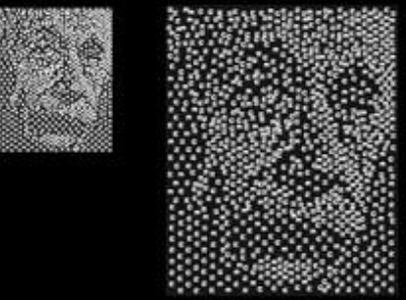
- ◆ Mass and energy are interconvertible.
- ◆ The fundamental source of all energy in the universe is the . . . **conversion of mass into energy.**



THESE ARE THE MOST COMMON TYPES OF MASS. THEY ARE MADE OF ATOMS AND MOLECULES. THEY ARE MADE OF PROTONS, NEUTRONS, AND ELECTRONS. THEY ARE MADE OF QUARKS AND LEPTONS. THEY ARE MADE OF FIELDS. THEY ARE MADE OF ENERGY. THEY ARE MADE OF INFORMATION. THEY ARE MADE OF CONSCIOUSNESS. THEY ARE MADE OF EVERYTHING.

Slope:  
 $c^2$

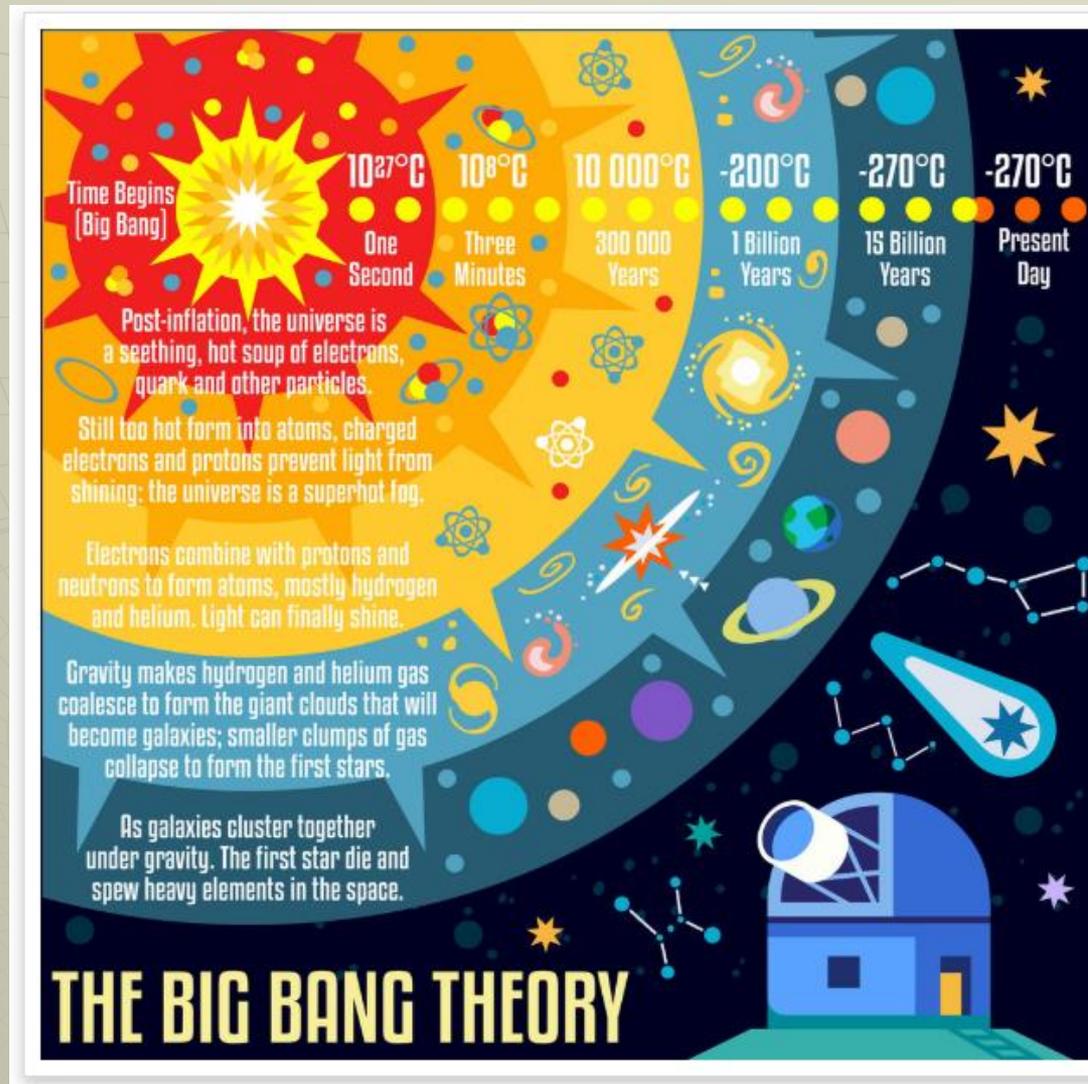
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# Energy-Mass Relationship



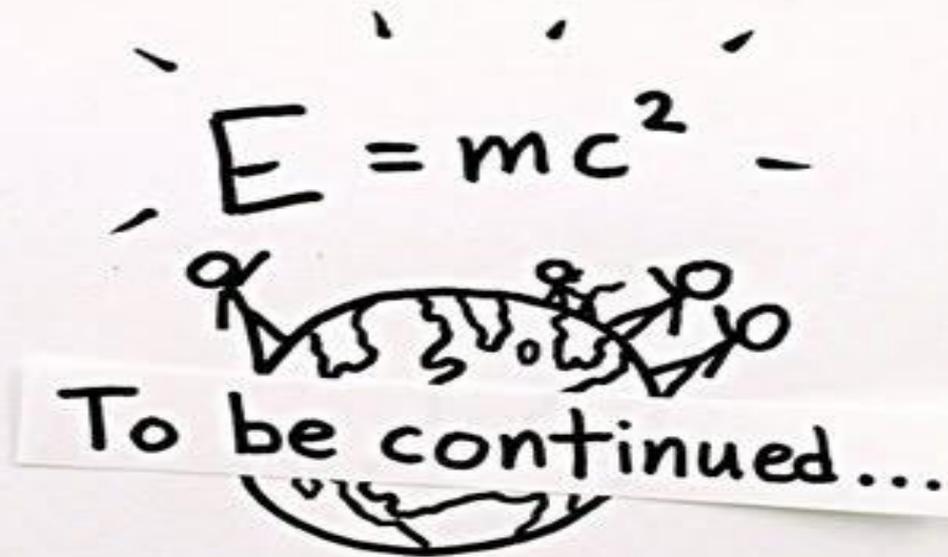
Where did all of the matter in the universe come from? [A question that has puzzled people for generations.](#)



The Big Bang Theory – conversion of matter into energy


$$E = mc^2$$

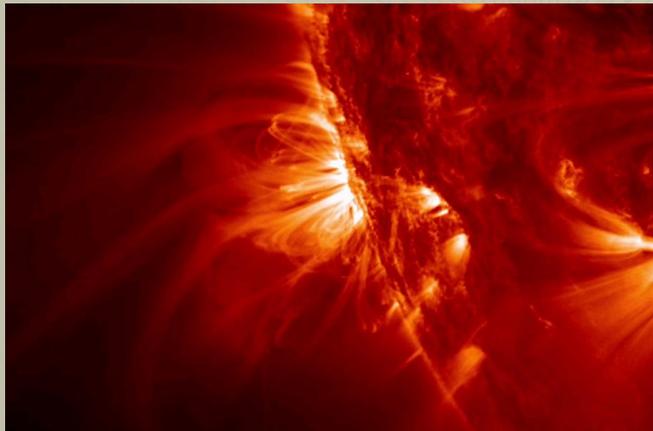
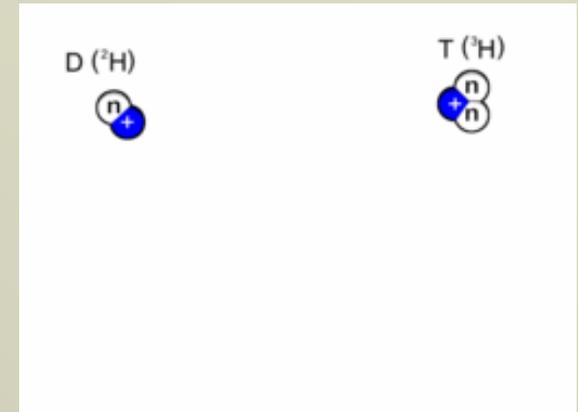

<https://www.youtube.com/watch?v=hW7DW9NIO9M>



<https://www.youtube.com/watch?v=NnMIhxWRGNw>

# Mass-Energy Relationship

- ◆ Fusion – combining atoms
  - Sun
  - Hydrogen bomb



Proton-proton fusion chain process

- 
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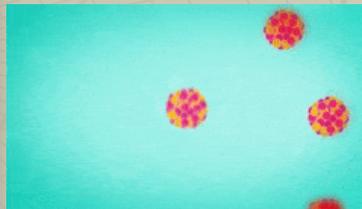
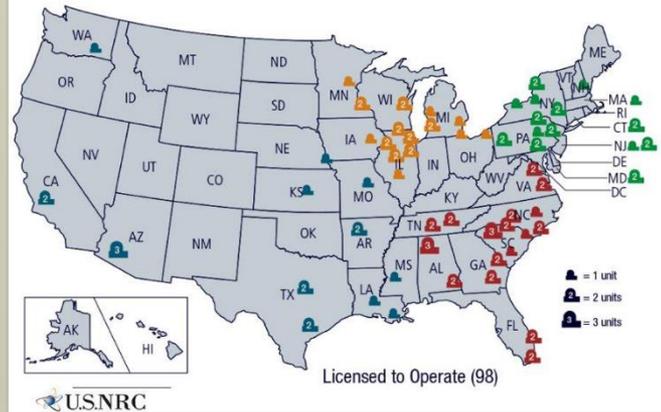
1st step: In two separate reactions, 2 protons in each reaction fuse



# Mass-Energy Relationship

- ◆ Fission – splitting atoms
  - Atomic Bombs
  - Nuclear reactor

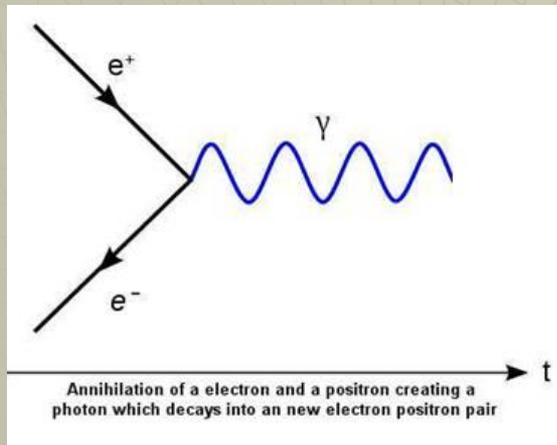
U.S. Operating Commercial Nuclear Power Reactors



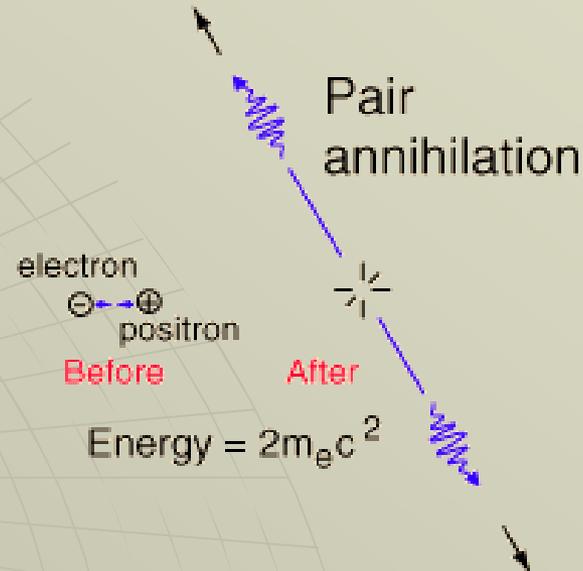
# Mass-Energy Relationship

- ◆ Pair Annihilation – particle and anti-particle turn into pure energy.

Feynman diagram



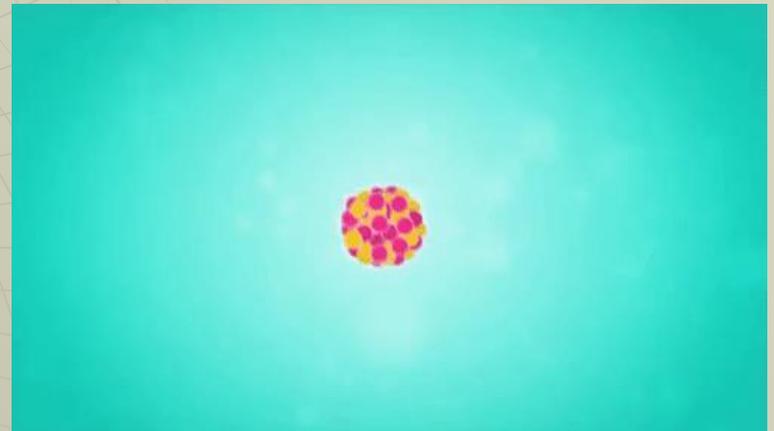
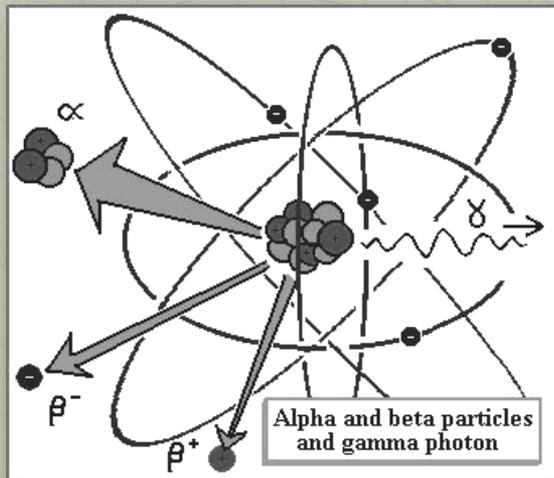
positron as if it were an electron moving **backward** in time



An antiparticle has the same mass, lifetime, and spin, but opposite charge as particle

# Mass-Energy Relationship

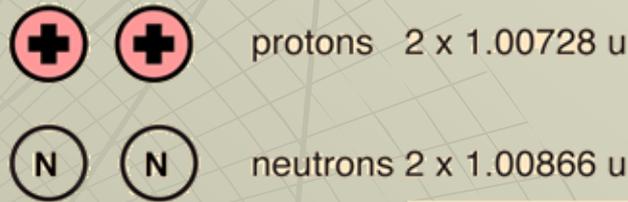
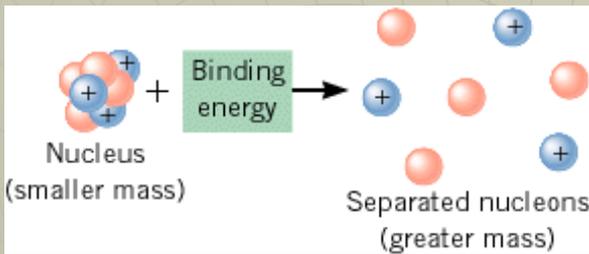
- ◆ Radioactive Decay – alpha, beta, gamma



Think back to chemistry

# Mass-Energy Relationship

## ◆ binding energy – formation of atoms



Mass of parts  $4.03188 \text{ u}$



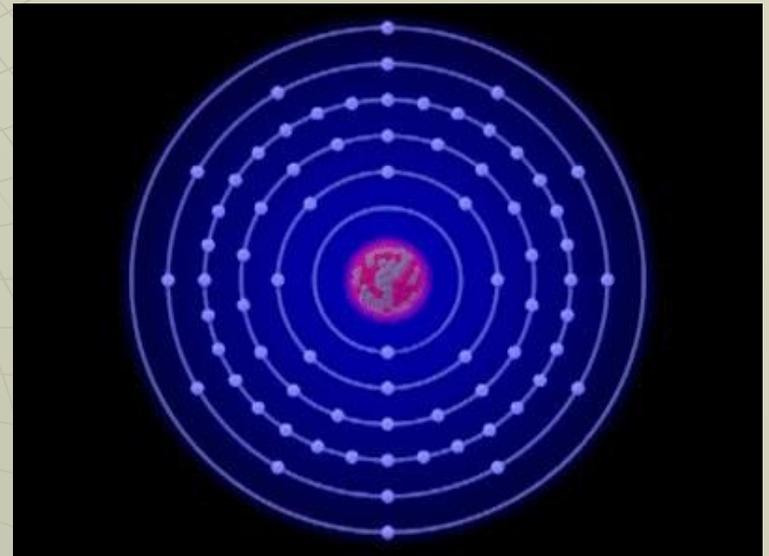
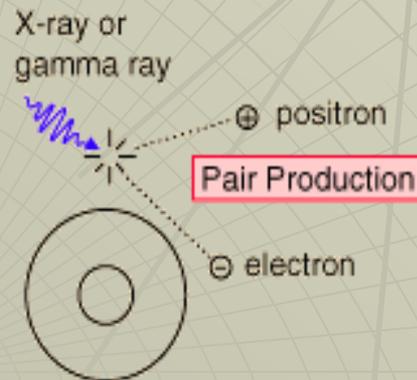
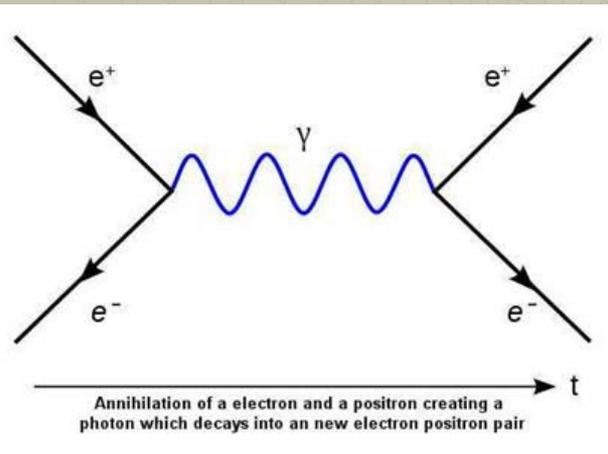
Mass of alpha  $4.00153 \text{ u}$

$$1 \text{ u} = 1.66054 \times 10^{-27} \text{ kg} = 931.494 \text{ MeV}/c^2$$

It takes energy to hold a nucleus together.

# Mass-Energy Relationship

- ◆ Pair Production - x-ray or gamma ray turn into electron and positron.



Determine the energy equivalent of the rest mass of a proton

The mass of a proton is on the front cover of your reference tables

Determine the energy equivalent of the rest mass of a proton

$$E=mc^2$$

$$= (1.67 \times 10^{-27} \text{ kg})(3.00 \times 10^8 \text{ m/s})^2$$

$$= 1.50 \times 10^{-10} \text{ J}$$

In a quantum process known as “pair production,” an electron and a positron are spontaneously created from energy.

A positron is an anti-electron.  
It has the same mass as an  
electron, so in  $E=mc^2$  you  
need twice the mass

In a quantum process known as “pair production,” an electron and a positron are spontaneously created from energy.

$$E=mc^2$$

$$= (1.82 \times 10^{-30} \text{ kg})(3.00 \times 10^8 \text{ m/s})^2$$

$$= 1.64 \times 10^{-13} \text{ J}$$

In a quantum process known as “pair production,” an electron and a positron are spontaneously created from energy.

$$1.64 \times 10^{-13} \text{ J}$$

The same amount of energy is created when the masses destroy each other

In a quantum process known as “pair production,” an electron and a positron are spontaneously created from energy.

## Energy/Matter and charge

Matter is a form of energy so only list it once

Charge – will not work with two of the same particle because of conservation of charge