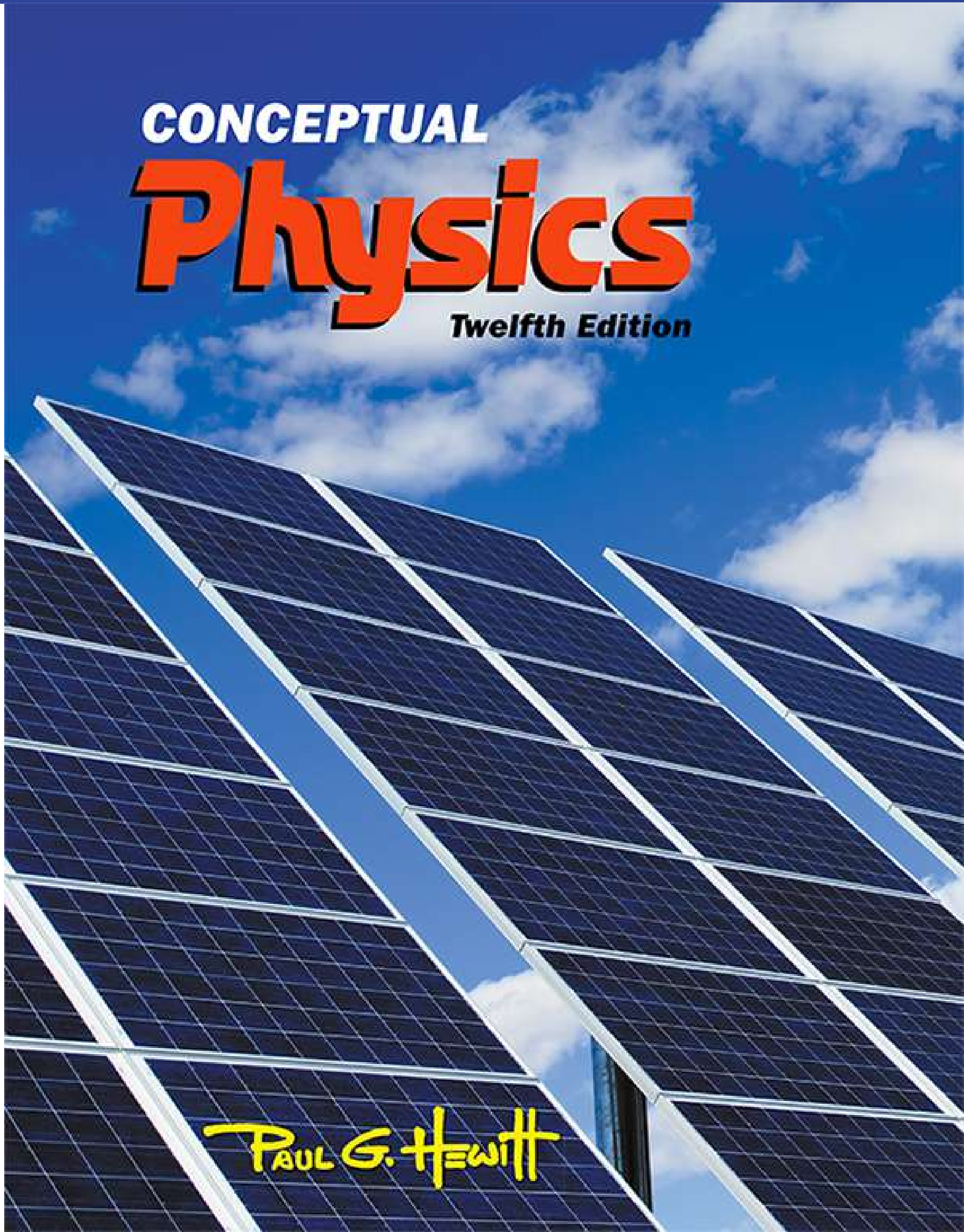
Lecture Outline



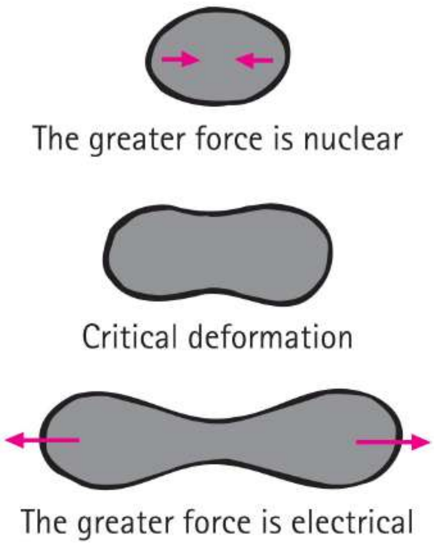
Chapter 34: Nuclear Fission and Fusion

This lecture will help you understand:

- Nuclear Fission
- Nuclear Fission Reactors
- Breeder Reactor
- Fission Power
- Mass–Energy Equivalence
- Nuclear Fusion
- Controlling Fusion

Nuclear Fission

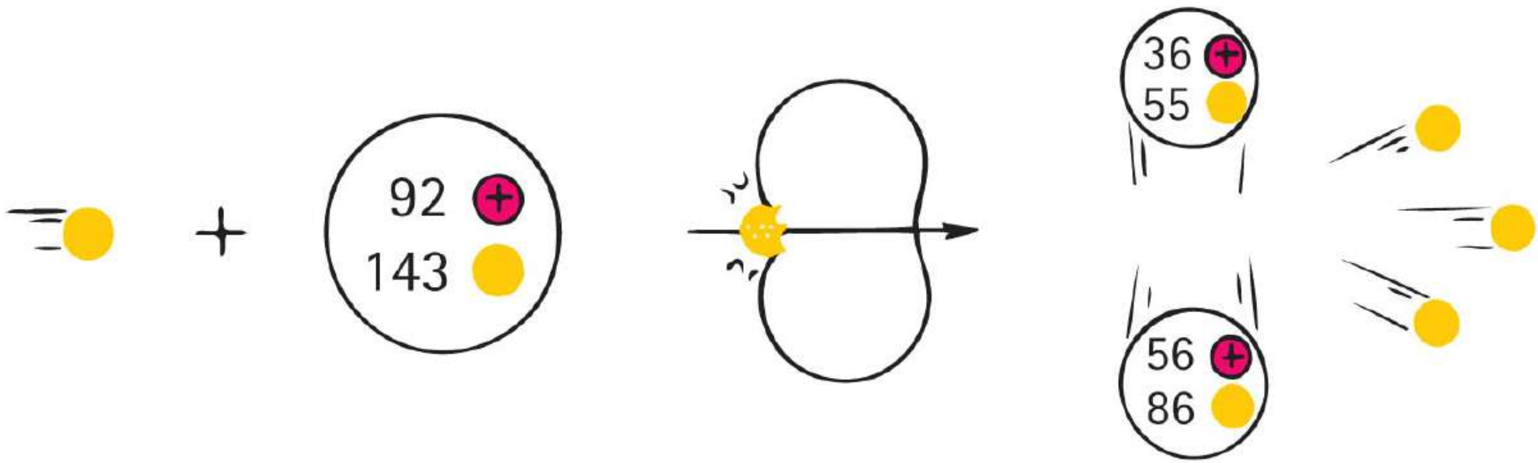
- German scientists Otto Hahn and Fritz Strassmann in 1938 accidentally discovered nuclear fission.



- Lise Meitner and Otto Frisch explained the process and gave it the name nuclear fission.

Nuclear Fission, Continued

- A typical uranium fission reaction:

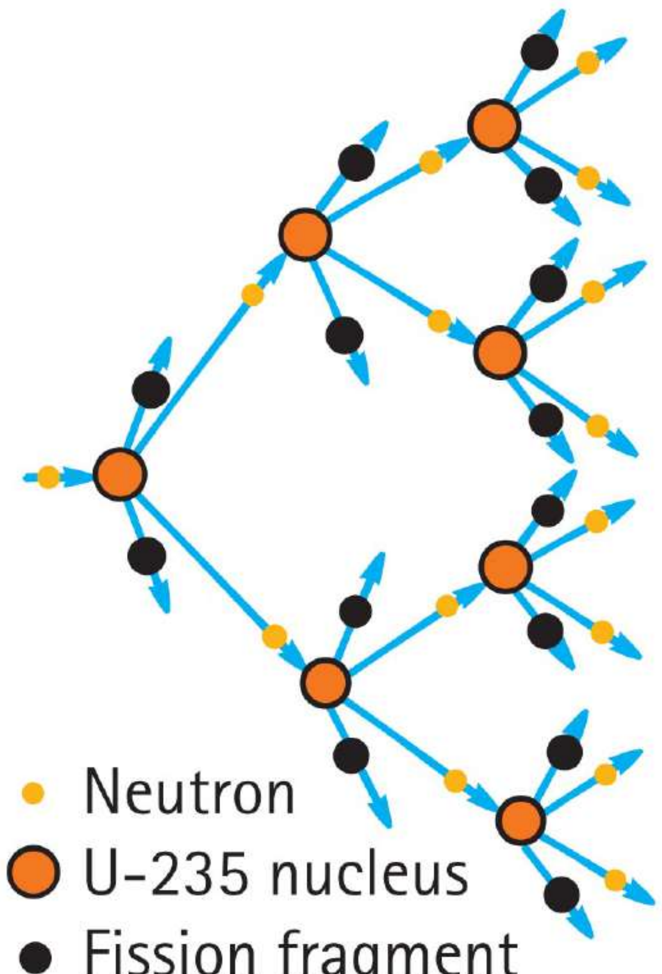


$$ {}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \rightarrow {}^{91}_{36}\mathrm{Kr} + {}^{142}_{56}\mathrm{Ba} + 3({}^{1}_{0}n) $$

- Note the mass number as well as atomic numbers balance.

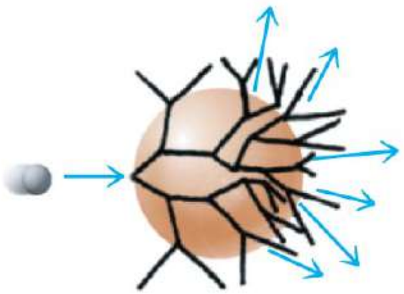
Nuclear Fission, Continued-1

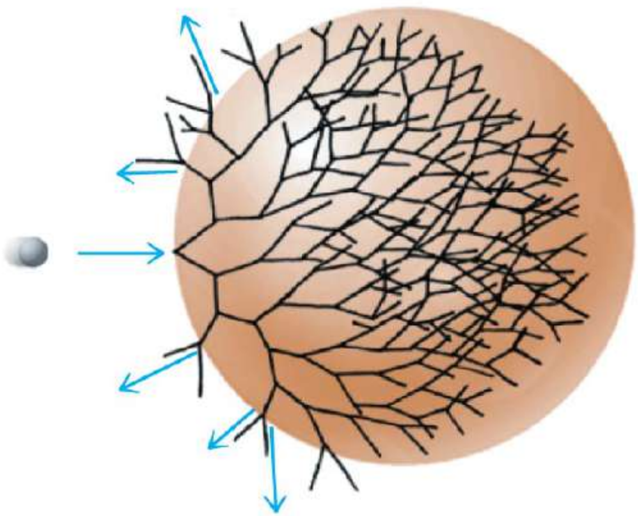
- Chain reaction—a self-sustaining reaction in which the products of one reaction event stimulate further reaction events



Nuclear Fission, Continued-2

- Chain reaction in uranium
  - Small amount, chain reaction fizzles.
  - Critical amount, chain reaction produces an explosion.





Nuclear Fission
CHECK YOUR NEIGHBOR

The greater the surface area of a piece of fission material, the

A. less likely an explosion.
B. more likely an explosion.
C. Neither A nor B; mass, rather than surface area is significant.
D. None of the above.

Nuclear Fission
CHECK YOUR ANSWER

The greater the surface area of a piece of fission material, the

A. **less likely an explosion.**

Explanation:

When a chain reaction occurs, it fizzles out when neutrons escape a surface. Therefore, the greater the surface area, the less likely an explosion will occur.

Nuclear Fission
CHECK YOUR NEIGHBOR, Continued

Which of these nuclei has the greatest mass?

A. Hydrogen
B. Iron
C. Lead
D. Uranium

Nuclear Fission
CHECK YOUR ANSWER, Continued

Which of these nuclei has the greatest mass?

D. **Uranium**

Nuclear Fission
CHECK YOUR NEIGHBOR, Continued-1

In which of these nuclei does the proton have the greatest mass?

A. Hydrogen
B. Iron
C. Lead
D. Uranium

Nuclear Fission
CHECK YOUR ANSWER, Continued-1

In which of these nuclei does the proton have the greatest mass?

A. **Hydrogen**

Nuclear Fission
CHECK YOUR NEIGHBOR, Continued-2

In which of these nuclei does the proton have the least mass?

A. Hydrogen
B. Iron
C. Lead
D. Uranium

Nuclear Fission
CHECK YOUR ANSWER, Continued-2

In which of these nuclei does the proton have the least mass?

B. **Iron**

Explanation:

A look at the curves of Figures 34.16-34.17 shows this. Iron has the least mass per nucleon, but the strongest binding energy.

Nuclear Fission
CHECK YOUR NEIGHBOR, Continued-3

When a uranium nucleus undergoes fission, the energy released is primarily in the form of

A. gamma radiation.
B. kinetic energy of fission fragments.
C. kinetic energy of ejected neutrons.
D. All of the above about equally.

Nuclear Fission
CHECK YOUR ANSWER, Continued-3

When a uranium nucleus undergoes fission, the energy released is primarily in the form of

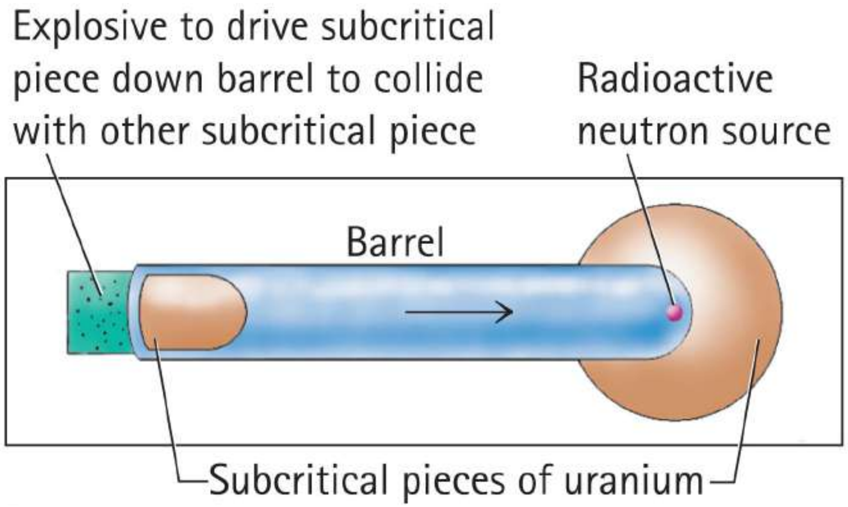
B. **kinetic energy of fission fragments.**

Explanation:

Kinetic energy of fragments is what becomes heat energy. Interestingly, gamma-ray energy is tiny in comparison. Neutrons, although important for the chain reaction, contribute a small part of the energy release. Choice D is likely a guess.

Nuclear Fission, Continued-3

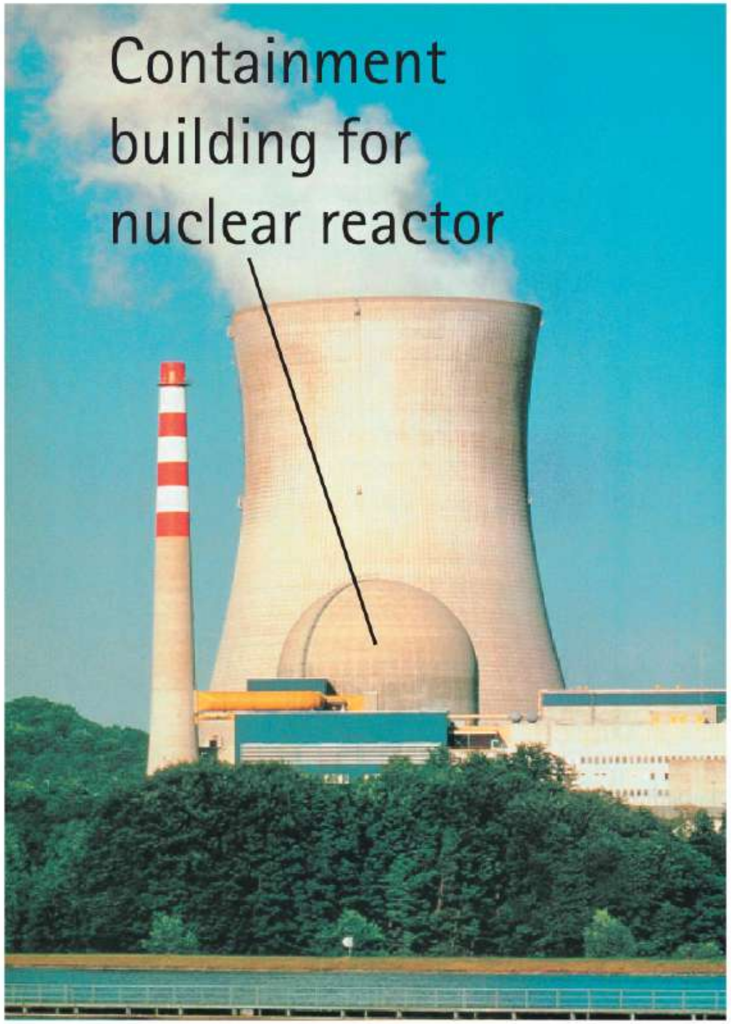
- Fission bomb



  – A bomb in which pieces of uranium are driven together is a so-called "gun-type" weapon, as opposed to the now more common "implosion weapon."
  – Constructing a fission bomb is a formidable task. The difficulty is separating enough U-235 fuel.

Nuclear Fission Reactors

- Nuclear fission reactors
  - About 20% of electric energy in the United States is generated by nuclear fission reactors.
  - More in some other countries—about 75% in France.
  - Reactors are simply nuclear furnaces that boil water to operate steam-driven generators.

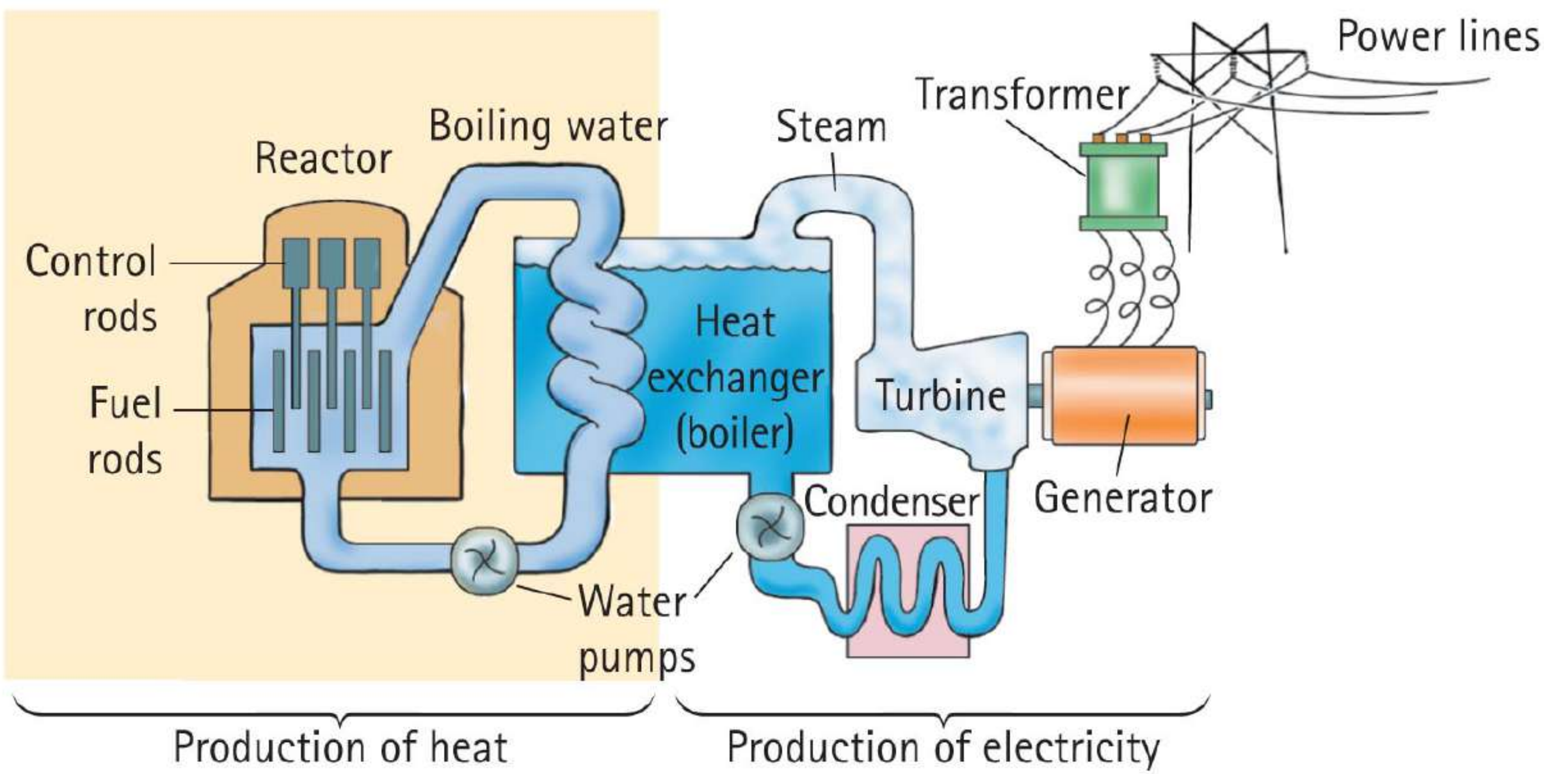


Nuclear Fission Reactors, Continued

- Today's fission reactors contain three components:
  - The nuclear fuel is primarily U-238 plus about 3% U-235.
  - The control rods are made of a neutron-absorbing material, usually cadmium or boron.
  - Water surrounding the nuclear fuel is kept under high pressure to keep it at a high temperature without boiling.

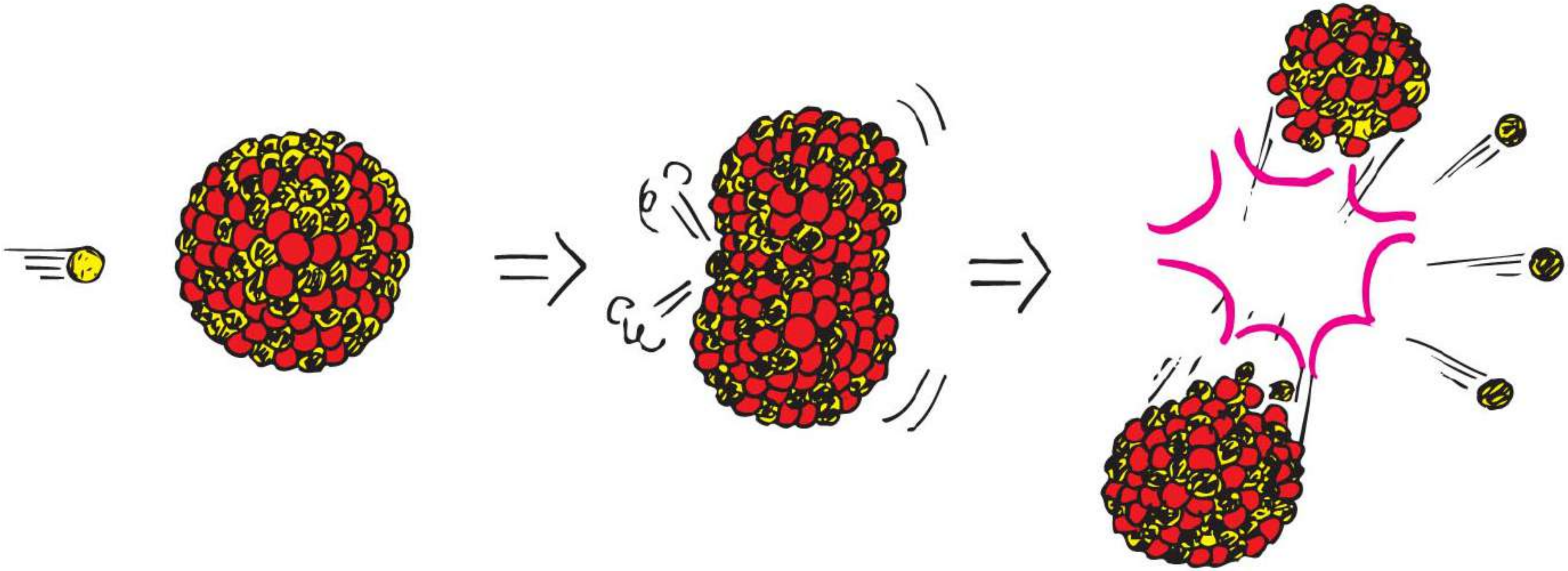
Nuclear Fission Reactors, Continued-1

- Diagram of a typical power plant:



Breeder Reactor

- Plutonium-239, like uranium-235, undergoes fission when it captures a neutron.



Breeder Reactor, Continued

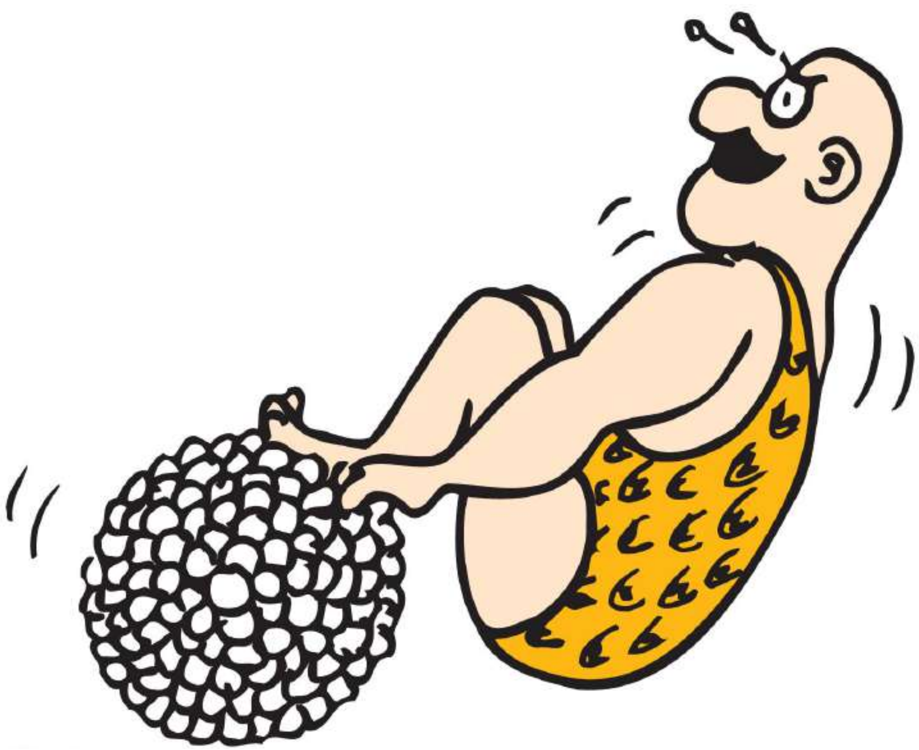
- The breeder reactor
  - A breeder reactor breeds Pu-239 from U-238 while "burning" U-235.
    - Occurs in all reactors to some extent.
    - In a few years can produce twice as much fissionable fuel as it begins with.
    - A more attractive alternative when U-235 reserves are limited.
    - Fuel for a breeder may be today's radioactive wastes.

Fission Power

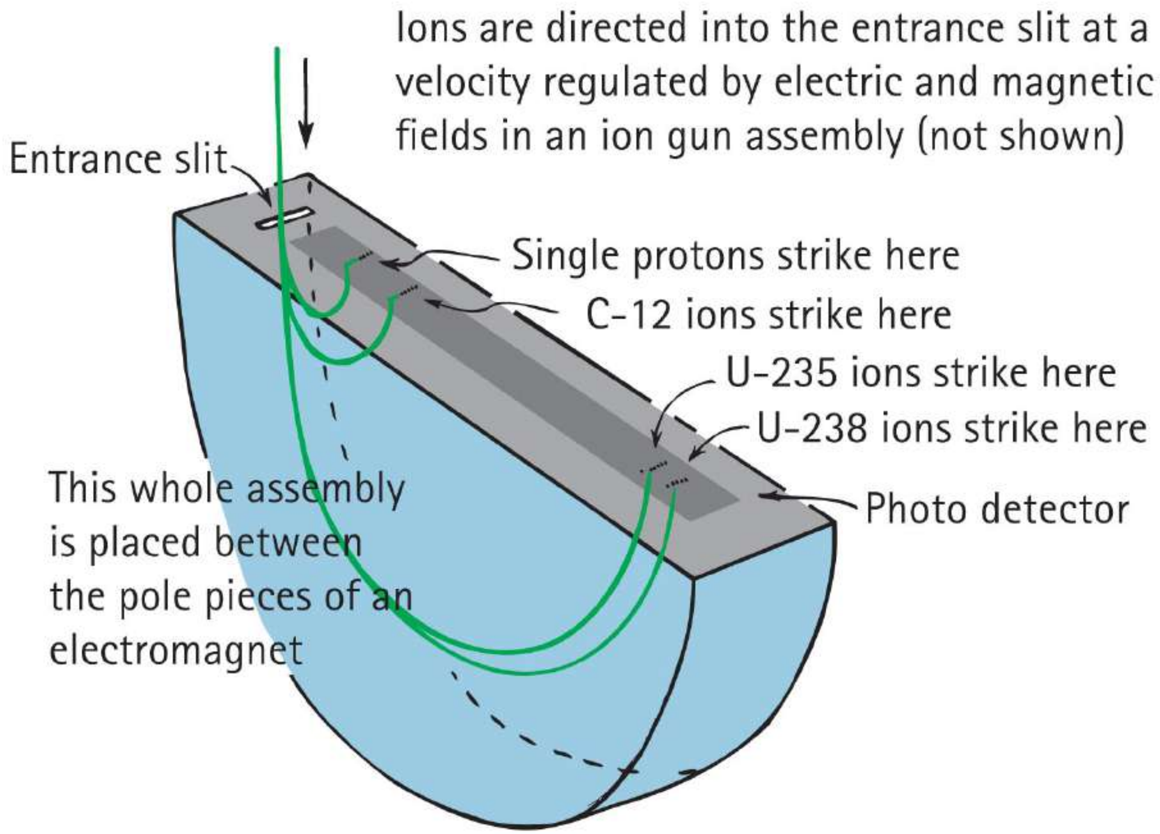
- The benefits are plentiful electricity, conservation of billions of tons of fossil fuels every year that are converted to heat and smoke (which in the long run may be far more precious as sources of organic molecules than as sources of heat), and the elimination of megatons of carbon dioxide, sulfur oxides, and other deleterious substances put into the air each year by the burning of fossil fuels.
- Drawbacks include risks of release of radioactive isotopes into the atmosphere, by accident or by terrorist activities. Radioactive waste disposal is a problem (although not for some countries that monitor it for potential use later).

Mass–Energy Equivalence—$E = mc^2$

- Early in the early 1900s, Albert Einstein discovered that mass is actually "congealed" energy.
- Enormous work is required to pull nucleons from a nucleus. This work is energy added to the nucleon that is pulled out.



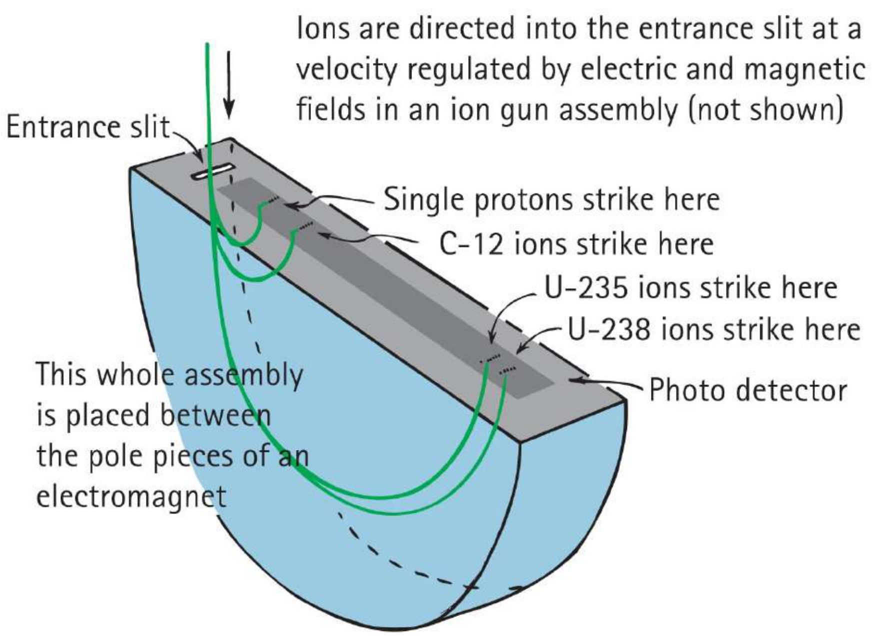
Mass–Energy Equivalence—$E = mc^2$, Continued



- Measurements of atomic mass are made with this device.

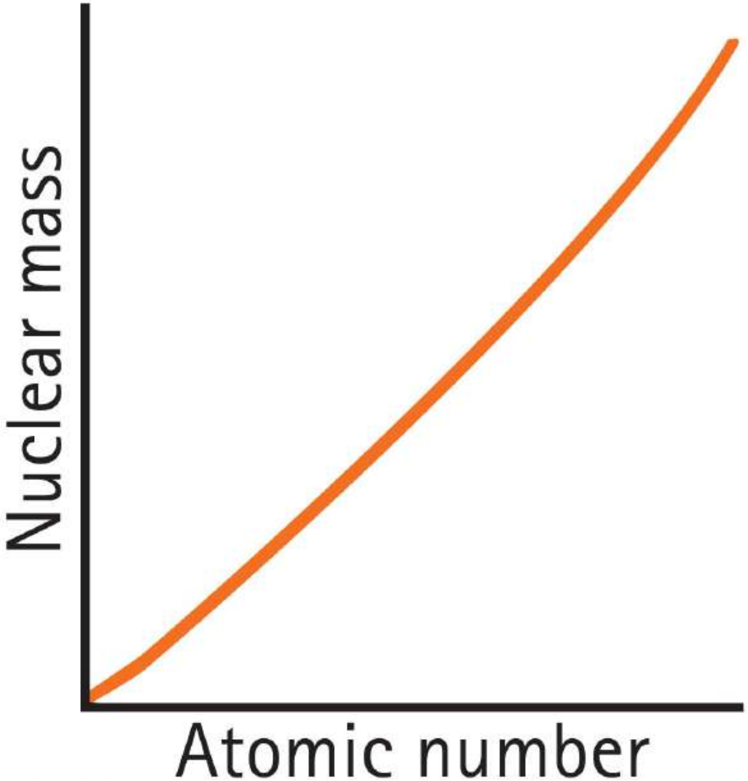
Mass–Energy Equivalence—$E = mc^2$, Continued-1

- Electrically charged isotopes directed into the semicircular "drum" are forced into curved paths by a strong magnetic field. Lighter isotopes with less inertia (mass) easily change direction and follow curves of smaller radii. Heavier isotopes with greater inertia (mass) follow larger curves. Mass of an isotope ~ distance from entrance slit.



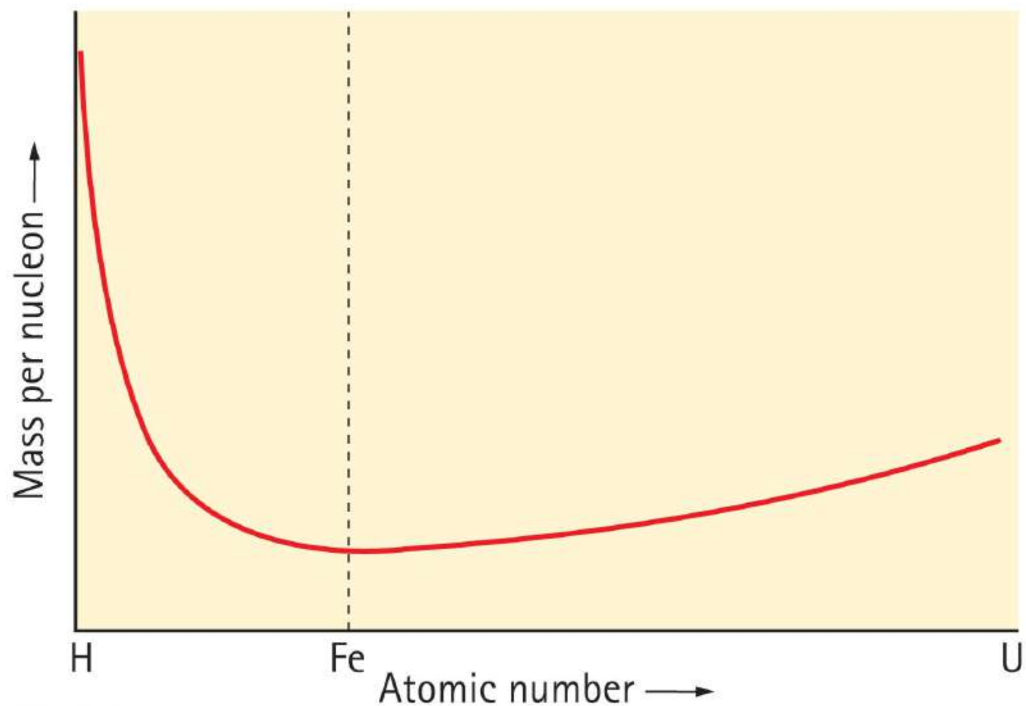
Mass–Energy Equivalence—$E = mc^2$, Continued-2

- The plot shows how nuclear mass increases with increasing atomic number.



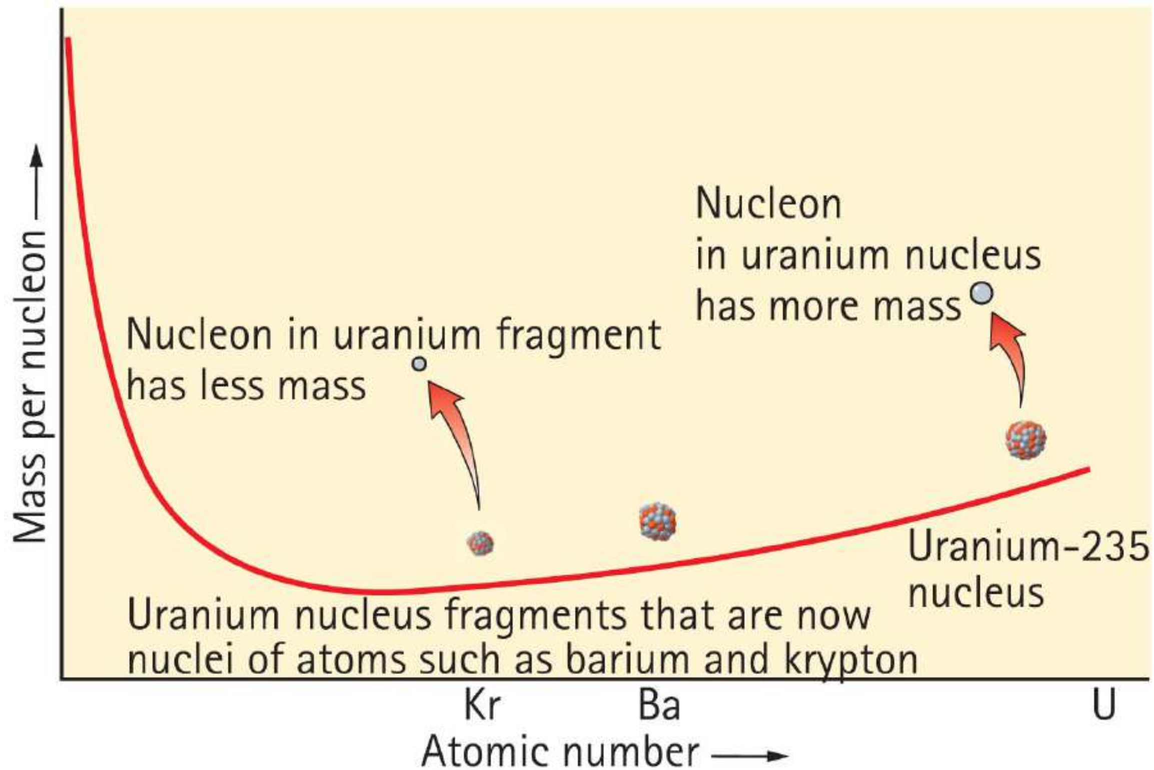
Mass–Energy Equivalence—$E = mc^2$, Continued-3

- A very important graph results from the plot of nuclear mass *per nucleon* from hydrogen through uranium.



Mass–Energy Equivalence—$E = mc^2$, Continued-4

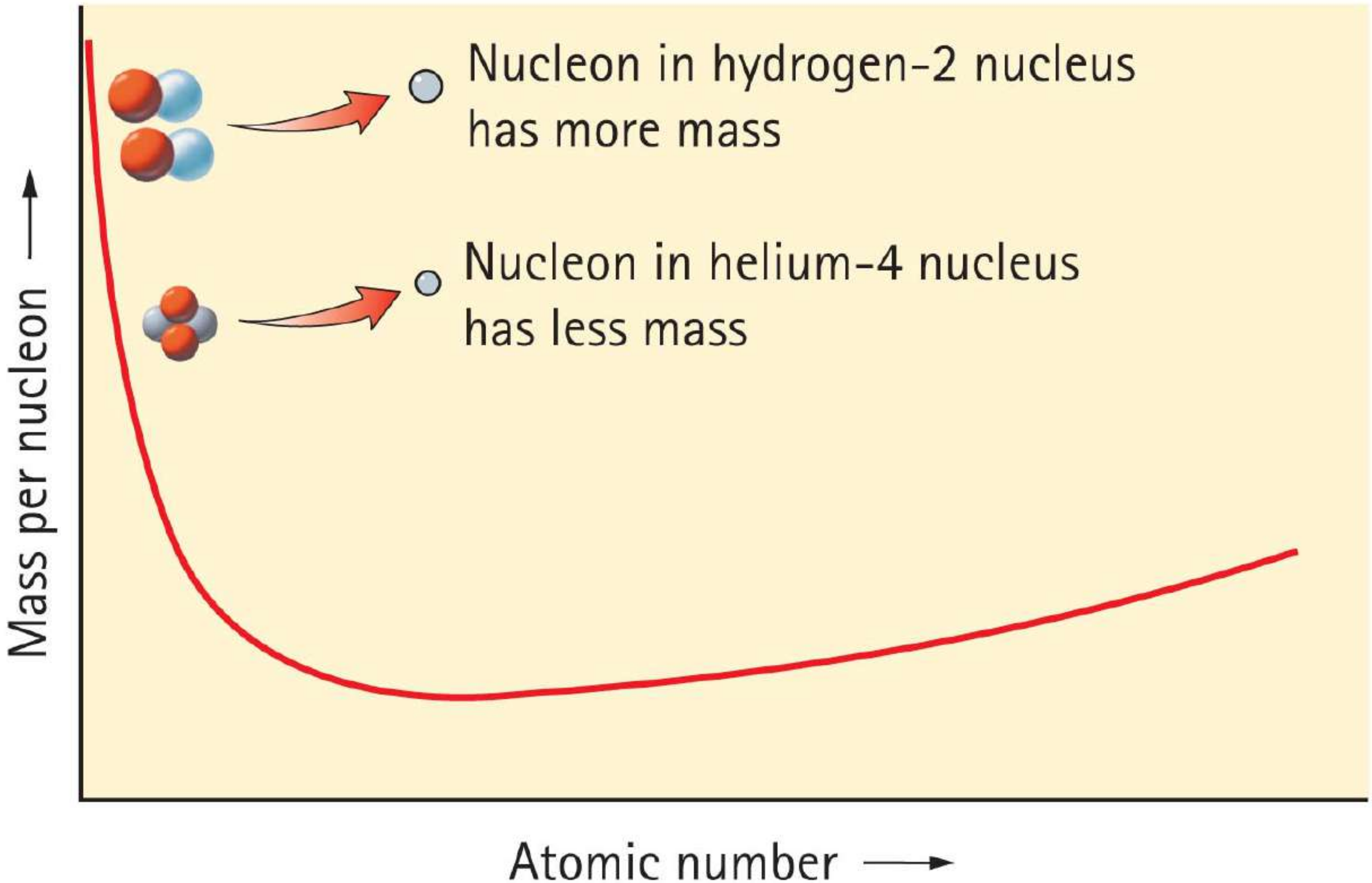
- The same graph, with emphasis on nuclear fission:



Nuclear Fusion

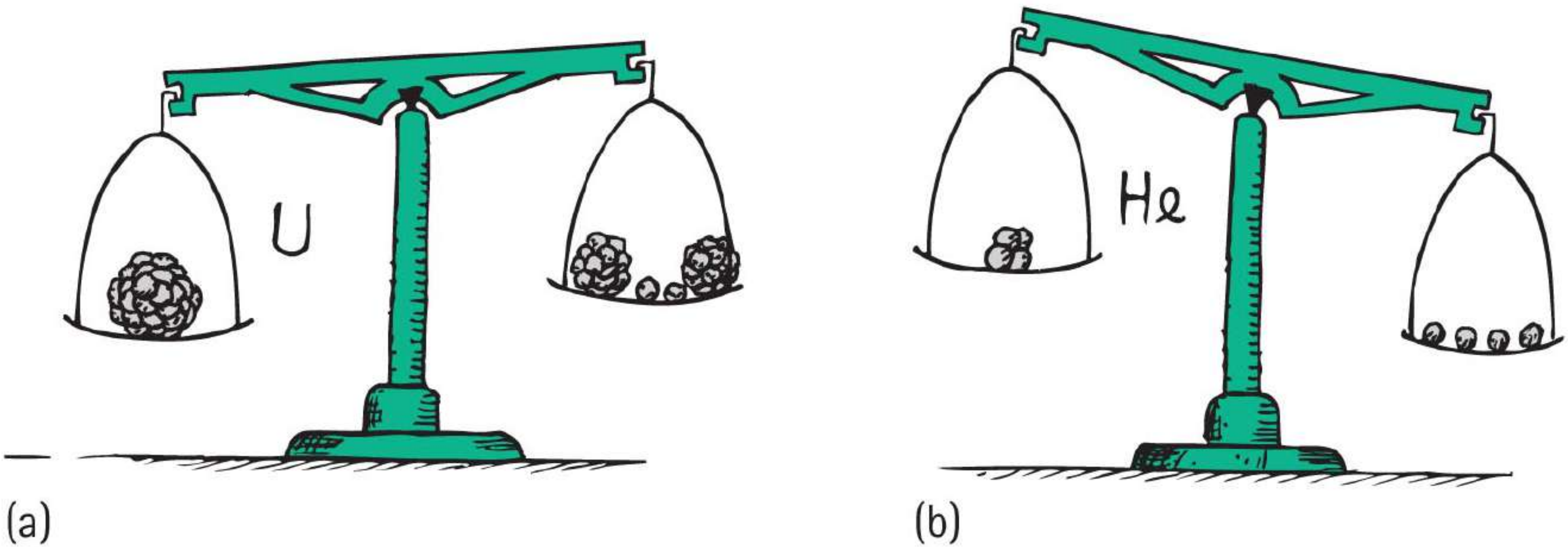
- Nuclear fusion is the opposite of nuclear fission.
- Fission: nuclei "fizz" apart.
- Fusion: nuclei fuse together.
- Each releases energy in accord with Figures 34.17 and 34.19.

Nuclear Fusion, Continued



Nuclear Fusion, Continued-1

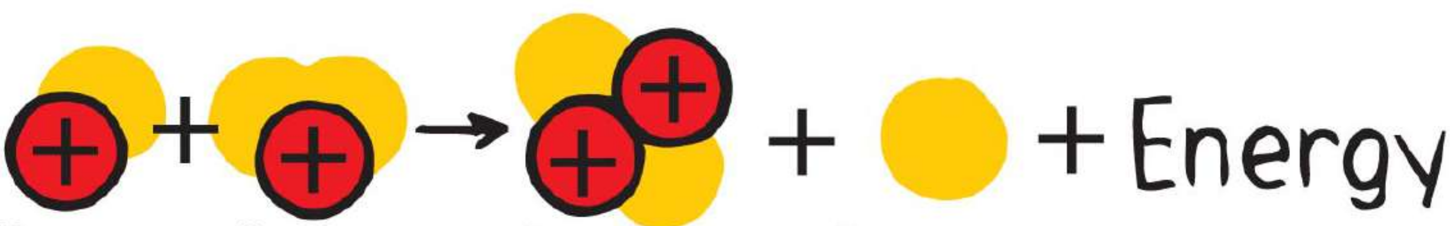
- Fission and fusion compared
  - Less mass per nucleon occurs in both processes.



Nuclear Fusion, Continued-2

- Typical fusion reactions:

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n} + 3.26\ \mathrm{MeV}$$



$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n} + 17.6\ \mathrm{MeV}$$

Nuclear Fusion
CHECK YOUR NEIGHBOR

When a fusion reaction converts a pair of hydrogen isotopes to an alpha particle and a neutron, most of the energy released is in the form of

A. gamma radiation.
B. kinetic energy of the alpha particle.
C. kinetic energy of the neutron.
D. All of the above about equally.

Nuclear Fusion
CHECK YOUR ANSWER

When a fusion reaction converts a pair of hydrogen isotopes to an alpha particle and a neutron, most of the energy released is in the form of

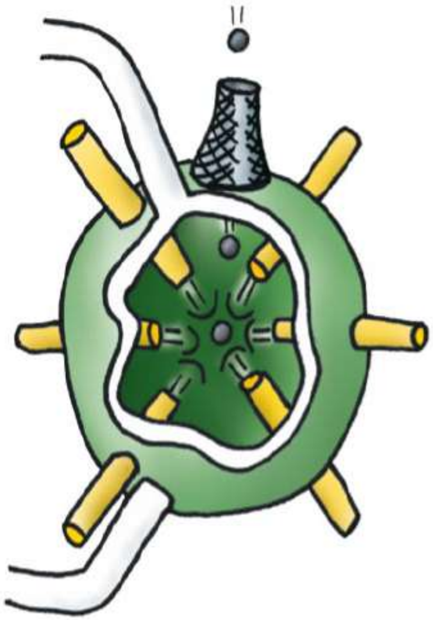
C. **kinetic energy of the neutron.**

Explanation:

By momentum conservation, the ejected neutrons have a high speed compared with the alpha particle, and therefore much kinetic energy. It is the kinetic energy of the neutrons that becomes the heat needed for power. Gamma rays play a small energy role, as they do in fission.

Controlling Fusion

- Carrying out fusion is more difficult than thought when fission succeeded.
  - Plasma reactors have not been successful.
  - Other schemes, including lasers, are being considered.
  - Deuterium pellets rhythmically dropped into synchronized laser crossfire; heat used to produce steam:



Nuclear Fission
CHECK YOUR NEIGHBOR, Continued-4

In either a fission event or a fusion event, the quantity that remains unchanged is

A. energy.
B. the mass of nucleons.
C. the number of nucleons.
D. None of the above.

Nuclear Fission
CHECK YOUR ANSWER, Continued-4

In either a fission event or a fusion event, the quantity that remains unchanged is

C. **the number of nucleons.**

Explanation:

This is a premise of reaction equations, whether nuclear or chemical. Although energy and mass undergo changes, the number of particles and amount of charge remain unchanged.