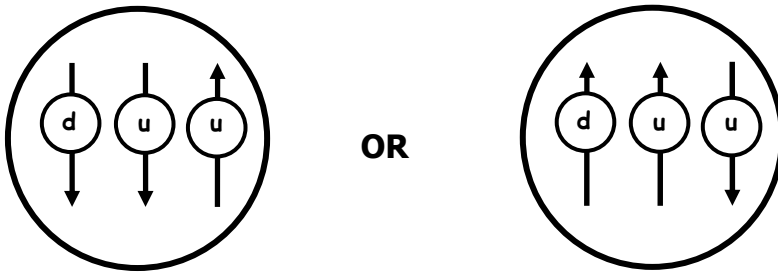


Activity 12 Solutions: Energy from Nuclear Reactions

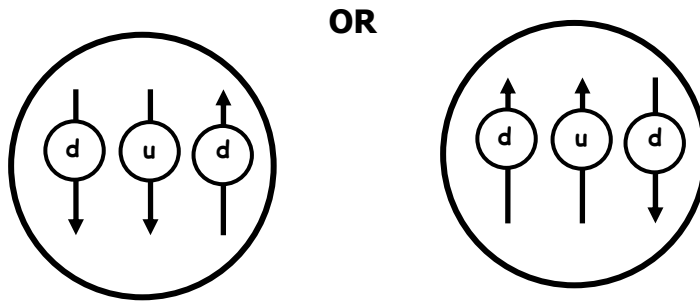
12.1 A Model of the Composition of Nucleons

1) **Formation of Nucleons** Nucleons consist of quark trios.

- a) Place orange or green "quarks" into the metal "nucleon" or "gluon cloud" to represent a proton. Draw a diagram showing the quarks in the proton.



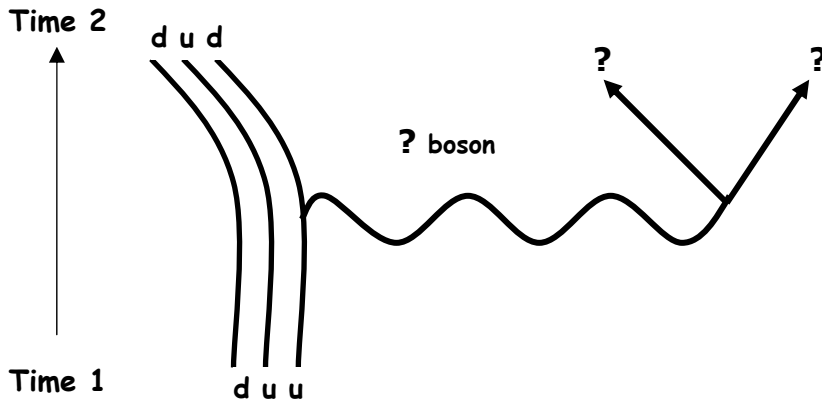
- b) Flip one of the "quarks" in the metal "gluon cloud" to represent a neutron. Make sure the spin of the neutron points in the same direction as the spin of the proton. Draw a diagram showing the quarks in the neutron.



- c) Which of the four fundamental forces is involved in binding quarks into nucleons?
the strong nuclear force
- d) The exchange of which type of gauge boson is responsible for binding quarks into nucleons?
the gluon

12.2 A Model of Beta Decay

2) **Feynman Diagram of a Beta Decay** Beta decays, in which a neutron changes into a proton or a proton changes into a neutron, can be represented by a Feynman diagram.



- Place the appropriate orange and green quarks into the gluon cloud to form the nucleon shown at Time 1. Which type of nucleon is this? **a proton**
- Flip the appropriate quark to form the nucleon at Time 2. Which type of nucleon is this? **a neutron**
- Open the black plastic box that correctly completes this reaction. Which box is this? **beta plus decay**
- Is an electron or an antielectron emitted? Why?

A positive antielectron is emitted to satisfy conservation of electric charge (+1 charge on each side of the reaction)

- Is a neutrino or antineutrino emitted? Why?

Since particles are emitted in matter-antimatter pairs, a neutrino is emitted with an antielectron.

- Write the nuclear reaction illustrated by this Feynman diagram.



- Which of the four fundamental forces is responsible for beta decay?

the weak nuclear force

- Which type of boson is responsible for beta plus decay? **a W^+ boson**

- Group Discussion Question: What changes occur in the identity of the quark trio making up the nucleus when a proton becomes a neutron? Why?

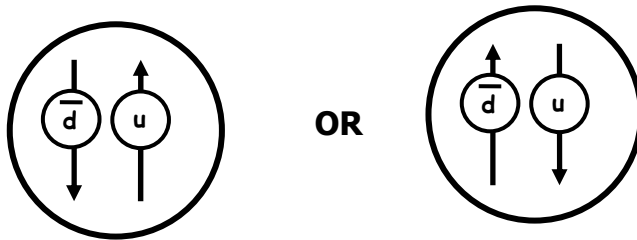
3) **Summary of beta decay** Fill in the table below to summarize the discussion of beta decay.

Decay	Nucleon change	Quark change	Particles emitted	Force involved	Gauge boson
beta-plus (β^+)	Proton into a neutron	Up quark into a down quark	Antielectron and neutrino	Weak	W^+
beta-minus (β^-)	Neutron into a proton	Down quark into up quark	Electron and antineutrino	Weak	W^-

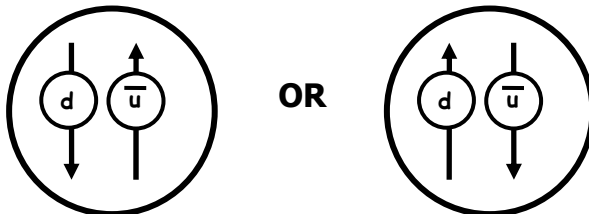
12.3 How Are Nucleons Bound into Nuclei?

4) **Pions** Your instructor will discuss pions, which consist of two quarks.

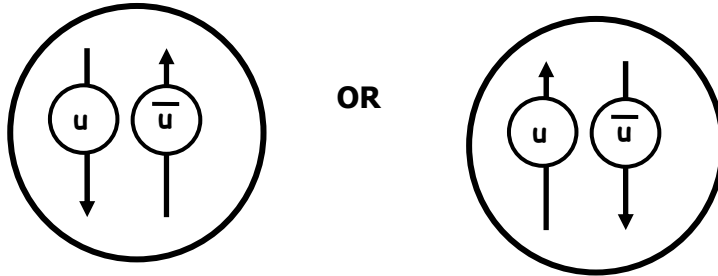
- a) Which quark and antiquark can form a positive pion? Draw a diagram showing this pair and the directions of their spins.



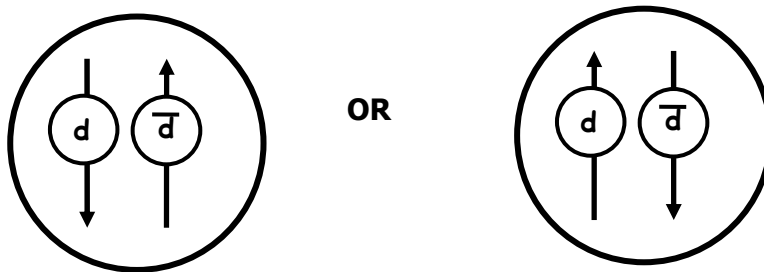
- b) Which quark and antiquark can form a negative pion? Draw a diagram showing this pair and the directions of their spins.



- c) Which quark and antiquark can form a neutral pion? Draw a diagram showing this pair and the directions of their spins. (There are two combinations of a quark and an antiquark that form a neutral pion. Draw diagrams of both combinations.)



AND



- d) Which of the four fundamental forces is responsible for binding quarks and antiquarks into pions?

the strong nuclear force

12.4 Nuclear Binding Energy

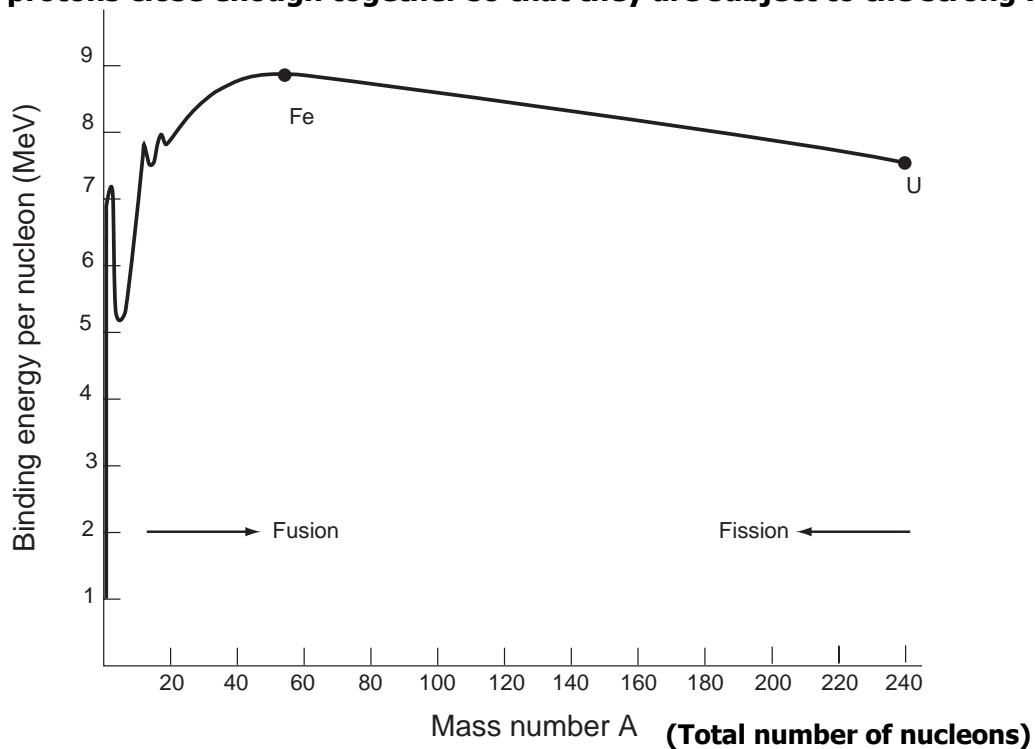
1) Releasing energy from nuclear decay

- a) Open the plastic boxes representing beta plus decay, beta minus decay, and gamma decay. What reaction product do each of these decays have in common? **__energy is released__**
- b) Name three other nuclear reactions that release energy.
1) alpha decay; 2) nuclear fusion, which occurs when nucleons fuse into a nucleus; and 3) nuclear fission, which occurs when an unstable nuclei breaks into smaller fragments
- c) What is the one nucleus naturally occurring that fissions spontaneously (without the addition of activation energy)?
uranium-235 ($^{235}_{92}\text{U}$)

2) Releasing energy from fusing matter

- a) When two protons come together, one proton can change into a neutron. The proton and neutron can then bind together to form one deuterium nucleus. For each deuterium nucleus formed, 3.52×10^{-13} joules of energy are given off. What is this energy called? **the binding energy of the deuterium nucleus**
- b) What is the process of nucleons binding called? **_fusion_**
- c) Why would you expect the process of forming a deuterium nucleus from two protons to require a large amount of activation energy?

The two positive protons repel one another. Energy is required to push the protons close enough together so that they are subject to the strong force.



12.5 Nuclear Reactions Produced in the Laboratory

3) Nuclear accelerators

- a) Are naturally-occurring nuclear reactions endothermic or exothermic?
Exothermic
- b) How can activation energy be supplied to produce nuclear reactions?

Particles can be given kinetic energy by accelerating them with an electric force. When accelerated particles are allowed to collide, some of their kinetic energy provides the activation energy needed to begin nuclear reactions.

- c) In addition to providing activation energy, what other function do accelerators play in particle physics?

Accelerators can provide energy for endothermic nuclear reactions. Such endothermic reactions include the production of unstable particles that do not occur in nature.

- d) What is the advantage of a circular particle accelerator?

Accelerating particles in a large circle provides a longer acceleration track in less space.

- e) Which type of particle accelerator could provide the most energy to colliding particles: a linear accelerator, a circular accelerator, or two accelerators?

Two accelerators combined provide the most energy because they can accelerate two beams of particles that collide into one another, producing about twice the energy of a single accelerator.

- f) Group Discussion Question: Nuclear fission occurs in nuclear reactors. Why don't we have nuclear fusion reactors?

12.6 Nuclear Reactions in Stars

4) Fusion reactions in stars

- a) What is the source of energy in stars such as the Sun? **nuclear fusion**
- b) Major challenges to controlling nuclear fusion reactions on Earth are providing the activation energy and containing the reactants. What force provides the activation energy and contains the reactants in fusion reactions in stars?

the force of gravity pulling matter inward toward the core of the star

- c) What is the proton-proton fusion chain?

In stars smaller than 1.2 times the mass of the Sun, two hydrogen nuclei fuse to form a nucleus of deuterium. Deuterium fuses with another hydrogen to form tritium, an isotope of helium. Two tritium fuse to form stable helium plus two hydrogen nuclei.

- d) Where does nuclear fusion occur in a star? **in the star's core**

- e) How does the energy from fusion reach the star's surface?

Energy is radiated through the star's radiative zone and is then transferred primarily by convection through the star's convective zone to its surface.

5) Formation of chemical elements in stars

- a) What is the origin of most of the hydrogen, helium, and lithium in the Universe?

These elements were created during the Big Bang origin of the Universe.

b) What is the origin of carbon?

Two alpha particles (He nuclei) fuse into an unstable isotope of beryllium. If a third alpha particle is added before the unstable beryllium nucleus decays back into two alpha particles, carbon is formed.

c) How are heavier elements through iron formed?

Stars more massive than 5 times the mass of the Sun collapse so violently that they begin fusing heavier elements. These stars fuse increasingly massive elements until iron is produced.

d) How are elements heavier than iron formed?

After burning (fusing) is completed in heavier stars, they collapse one last time. These stars explode violently in a type II supernova and release so much energy that endothermic fusion reactions of heavy elements can occur.

e) Group Discussion Question: What is the origin of the heavy elements on the Earth?

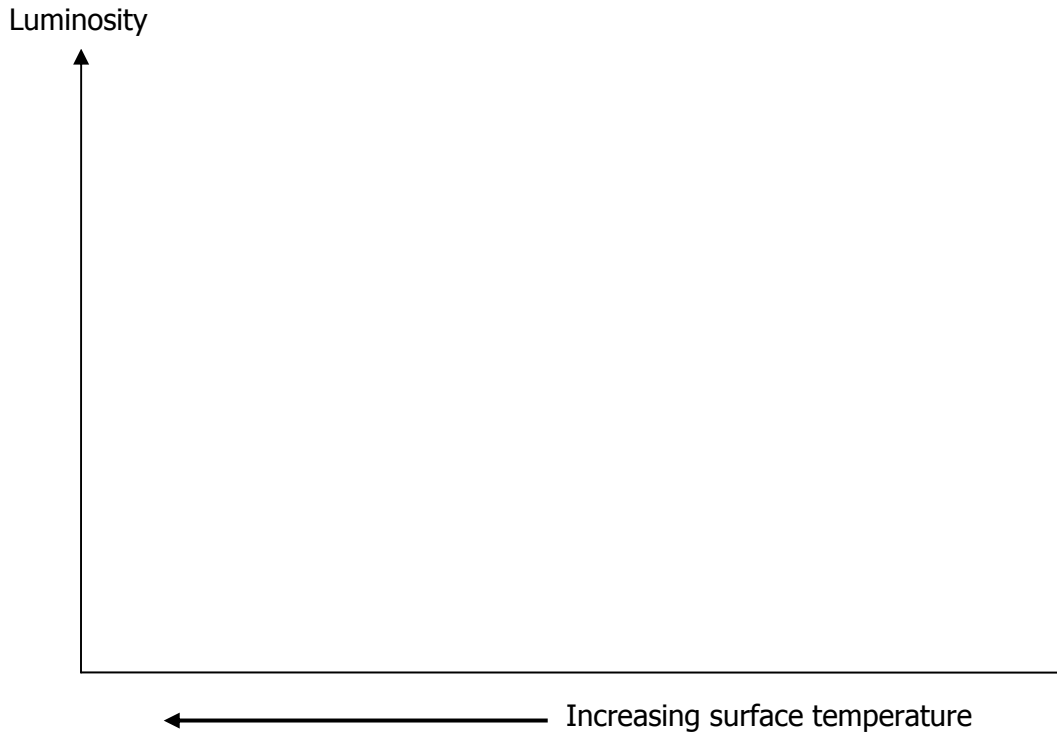
12.5 Types of Stars

6) The Hertzsprung Russell (H-R) diagram of stars

a) Place each metal disk, which represents a star, on the appropriate point of the grid of the H-R diagram that corresponds to the star's temperature and luminosity (brightness).

Note that the temperature on the horizontal axis increases as one moves to the left. The axes are logarithmic scales, therefore the spacing between temperatures on the horizontal scale is not linear.

b) Indicate on the diagram below approximately where you have placed the disks. Include information on the color of the disk and its size.



- c) Explain the change in color of the stars in the main sequence.

The color of stars is related to the star's surface temperature. Higher temperature stars radiate more energetic photons with shorter wavelengths. Cooler stars radiate longer wavelength photons. As a result, star colors range from blue for the hottest stars to red for the cooler stars.

- d) Sirius is one of the brightest stars in the northern hemisphere's sky. What color is Sirius? How does its temperature compare to the temperature of the Sun?

Sirius is blue-white. From the H-R diagram, its temperature is 10,000 K or greater. Therefore, Sirius is much hotter than the Sun, which has a temperature of approximately 6,000 K.

- e) What are the small stars in the lower left corner of the diagram?

These stars are white dwarfs, which began as stars with less than 5 times the mass of the Sun. White dwarfs cannot produce elements more massive than oxygen. They collapse into small stars with a high surface temperature, but not much total light.

- f) What are the large red stars in the upper right corner of the diagram?

These red giant stars have collapsed and their mantle of matter has blown outward. Red giants have a small and rapidly burning core that is surrounded by a larger cooler red outer mantle.

- g) Group Discussion Question: Are any white dwarf stars visible from Earth? Are any red giant stars visible from earth?