INDEPENDENT STUDY

Fuels, Energy & Nuclear Chemistry

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Presented to Mrs. Pall
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Table of Contents

Part 1: Chemistry Today I

Section 1

Read Chapter 17, pp 585-611

Goals

Be able to:

1. Describe the properties of radioactive substances such as compounds of radium.
2. List the properties of alpha, beta and gamma rays.
3. List the four types of nuclear reactions and give an example of each.
4. Balance nuclear equations.
5. Describe the operations of the CANDU nuclear reactor.
6. Discuss the benefits and the hazards associated with the production of nuclear energy for commercial and military purposes.

Part One: The Principles of Nuclear Chemistry

1- Radioactivity
Discovered 1896; Henri Becquerel
A. Uranium ore caused a covered photographic plate to become fogged.
B. Decided that uranium emits rays capable of penetrating black paper and thin sheets of metal. The property of giving off rays = radioactivity
Marie and Pierre Curie
C. Pitchblend more radioactive that uranium
D. Concentrated material in it and discovered Polonium.
E. Marie Curie isolated Radium
F. Her thesis was declared greatest achievement in the history of science. (Nobel Prize)
G. 2nd Nobel Prize for isolating Radium from radium chloride

2- 2.Properties of a Radioactive Element - Radium
Rays penetrate paper, wood, flesh and thin metal sheets.
Discharge an electroscope
H. Rays ionize the gas (air) in the electroscope by knocking off the outer electrons.
I. The resulting charged ions are able to conduct electricity and the charge is removed.
Geiger-Mullen Tube
J. Measure the rays
K. Rays enter the gas contained tube through glass envelope.
L. Energy from the rays ionizes the gas molecules in teh tube
M. Electrons and positive ions formed are attracted to charged electrodes.
N. When hit electrode, a pulse is created.
O. Pulses counted in Geiger Counter
Radium + Compound (Zinc Sulphide) glow in the dark
Radium Salt glows in dark (emitting energy)
Radium Salts give off enough heat to melt 1.5 times its mass of ice.

3- The Lead Block Experiment

Lord Rutherford
Radium Salt in led block
Zinc Sulfide Screen (luminous when struck by radiation)
Magnet in path of radiation.
Three Streams of Particles

P. Positive Charge = Alpha
- Helium Nuclei (2 protons / 2 neutrons)
- Charge 2+
- Mass 4u
- Speed 0.05 Light
- Weak penetrating power
  1. Range of few cm in air
  2. Stopped by thin sheets of aluminum or paper
- Ionize gas molecules through which they pass

Q. Negative Charge Beta
- High-Energy electrons
- Negative Charge
- Speed 0.3 - 0.99 Light
- Greater penetrating power
  1. Several millimeters of Aluminum
- Do not ionize gas molecules as well as alpha particles

R. Uncharged = Gamma Rays
- No charge
- Not particles
- High-energy, high-frequency electromagnetic radiations (similar to x-rays)
- Speed = Light
- Very penetrating
  1. 5 cm lead
  2. 30 cm Steel
- Little ionizing effect on gases

4- Stability of the Nucleus

Radioactive = Atom with unstable nucleus that is emitting particles and rays as it breaks down into more stable nuclei.
Mass

S. Loss in Mass
- Helium Nucleus = 4.0015u
- Proton: 1.0073 u
- Neutron: 1.0087 u
- Helium Should be: 2(1.00730 u) + 2(1.0087 u) = 4.0320 u
- Loss of 0.0305 u

T. Mass Defect: The mass converted into energy when a nucleus is made from its components

U. Binding Energy: The energy produced when a nucleus is made from its components

V. +++ Binding Energy, +++ Stable

W. Less binding Energy for very heavy and very light nucleus. So less stable

X. All elements heavier than bismsuth are unstable
Y. Graph relation of binding energy to mass number
Z. Fe (56/26) is the most stable nucleus in nature.

p/n

AA. Stability of nucleus depends on proton-neutron ratio
BB. 1st 20 elements: 1:1 Ratio
CC. (56/26) Fe: 1:1.15
DD. (238/92) U: 1:1.59
EE. If p/n ratio not in the "belt," the nucleus is radioactive.

Radioactive nuclei emit particles.
In doing so, they achieve a p/n ratio that provides stability.
p/n ratio less by emitting alpha particles
p/n ratio is greater by emission of beta particles

Even-Odd Rule

FF. Even number neutrons / Even number protons = more stable
GG. Odd neutrons / Even protons = less stable
HH. Odd neutrons / Odd protons = very unstable
II. Some nuclei are unusually stable if they have a magic number of protons or neutrons:

Protons: 2, 8, 20, 28, 50, 82
Neutrons: 2, 8, 20, 50, 82, 126
Such elements tend to avoid chemical reactions.
One explanation is a quantum mechanics model claiming that only certain nuclear energy levels are allowed. The magic number may the number of nucleons that fill successive nuclear energy shells.

5- Balancing Nuclear Equations

One nuclei are represented

JJ. ${}^{12}_{6}C$

6: Protons
12: Protons and neutrons (mass number)

KK. Common particles

Name of Particle	Symbol
Alpha	${}^{4}_{2}He\ or\ \alpha$
Beta	${}^{0}_{-1}e\ or\ \beta^{-}$
Proton	${}^{1}_{1}H\ or\ p$
Neutron	${}^{1}_{0}n\ or\ n$
Deuteron	${}^{1}_{2}H$

Must ensure that:

LL. Sum of superscripts on left = right (conservation of mass)
MM. Sum of subscripts on left = right (conservation of charge)

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$
$$238 = 234 + 4$$
$$92 = 90 + 2$$

NN.

$$^{13}_{7}N + ^{0}_{-1}e \rightarrow ^{13}_{6}C$$

$$^{24}_{11}Na \rightarrow ^{24}_{12}Mg + ^{e}_{-1}e$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{38}Sr + ^{143}_{54}Xe + 3^{1}_{0}n$$
$$235 + 1 = 236 = 90 + 143 + (3 \times 1)$$
$$92 + 0 = 92 = 38 + 54 + (3 \times 0)$$

6- Types of Nuclear Reactions

Radioactive Decomposition: The altering of a nucleus by the loss of an alpha particle or beta particle.

Artificial Transmutation: The process of bombarding a nucleus with alpha particles, protons, or neutrons to give an unstable nucleus, which can emit a proton or neutron in order to gain stability.

Fission: The process wherein a heavy nucleus splits to form nuclei of intermediate mass.

Fusion: The process wherein two light nuclei combine to form a heavier, more stable nucleus.

7- Radioactive Decomposition

Alpha Decay

OO. Heavy nuclear break down to lighter nuclei.

PP. Alpha particles are emitted

QQ. Example

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

U becomes Th; lose 2p

77% of decay events; Ignoring other 23%

So, we write: $^{238}_{92}U \rightarrow ^{234}_{90}Th^* + ^{4}_{2}He$

$Then\ ^{234}_{90}Th^* \rightarrow ^{234}_{90}Th + Gamma\ Rays$

1. The thorium is excited (high energy) and loses in gamma rays.

Half Life $t_{\frac{1}{2}}$

1. Time for an atom to degenerate to ½ of its original number of nuclei.

Beta Decay

RR. Increase charge in nucleus by 1.

SS. Thorium from alpha decay is unstable (becomes protactinium)

$$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + ^{0}_{-1}e$$

TT. Where did the electron originate? Fermi suggests a neutron is transformed into a proton and an electron.

$$^{1}_{0}n \rightarrow ^{1}_{1}H + ^{0}_{-1}e$$

UU. Half life of Thorium = 24 days

VV. Pa decays into Uranium

$$^{234}_{91}Pa \rightarrow ^{234}_{92}U + ^{0}_{-1}e$$

WW. Uranium-234 decays by five alpha decays in a row to $^{214}_{82}Pb$

XX. Two beta, one alpha, two beta, one alpha decay to give $^{206}_{82}Pb$

YY. Lead-206 is stable, so the series ends.

ZZ. This a naturally occurring radioactive decay series.

AAA. All naturally occurring radioactive elements belong to one of the three series.

BBB. Alpha Decay: -4 amu
Intermediate mass better

CCC. Beta Decay: n → p
Brings ratio closer to one

8- Application of Natural Radioactivity
Minerals

DDD. U_3O_8 (Pitchblend) in pure crystal decays to some lead (can determined the length of time required for the solidification of rock, relation between amount of lead and time)

EEE. Can also use $^{40}_{19}$K and $^{40}_{18}$Ar to determine age of minerals…used to find age of solar system.
Carbon Dating

FFF. Radioactive carbon-14 produced by bombardment of atmospheric nitrogen by neutrons from cosmic rays:

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}H$$

GGG. "The concentration of radioactive $^{14}CO_2$ in the atmosphere is kept in balance by the constant production of carbon-14 and decay of carbon-14 back to nitrogen-14.

HHH. Living things have carbon-14 and balance upset when they die.

III. Carbon-14 decays w/o being replaced.

JJJ. Carbon-14 half-life 5570 years

KKK. Can calculate how long ago death took place.

Part Two: Splitting the Atom

9- Artificial Transmutation
Rutherford did first (1919)

LLL. Bombarded nitrogen atoms with alpha particles from a radium source.

MMM. Protons and oxygen isotope produced

NNN. $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

Worked for elements up to potassium.
Since 2+ Charge on He, larger elements repelled them.
If a proton was used (1+), maybe it could enter the nucleus more easily.
1932 – John Cockcroft and Ernest Walton tried lithium with high-energy protons by ionizing H gas.

OOO. $^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He + energy$

1932 – James Chadwick attempted alpha particles on Be

PPP. Particle of mass 1u obtained – the neutron

QQQ. $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$

10- Particle Accelerators

Energy needed for artificial transmutation can be acquired as kinetic energy.
Be needs alpha particles at 2-3% speed of light.
Cyclotrons and Linear Accelerator use magnetic and electric fields to accelerate particles.
Used in vacuum.

11- Neutrons Are Better Bullets

Before neutrons discovered, had to use alpha particles, deuterons and proton. (all with charges, so needed high speeds)
Neutrons have no charge and can penetrate nuclei more easily.
Neutrons must be slowed down before they can absorbed by other atoms (causing nuclei to disintegrate)
Fast neutrons lose E_K when collide with atoms, which slow the neutrons w/o absorbing them or reacting with them.

RRR. E.g. D_2O (Heavy Water), graphite, CO_2, H_2O

To get neutrons:

SSS. ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + {}^{1}_{0}n$

Examples of forming new elements with artificial transmutation (followed by decay)

${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U$

TTT. ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e$

${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}e$

UUU. ${}^{59}_{27}Co + {}^{1}_{0}n \rightarrow {}^{60}_{27}Co$

Cobalt-60 is radioactive

VVV. ${}^{32}_{16}S + {}^{1}_{0}n \rightarrow {}^{32}_{15}P + {}^{1}_{1}H$

Phosphorus-32 is radioactive

Transuranium Elements: More than 92 protons in their nuclei

WWW. Neptunium

XXX. Plutonium

Radioactive isotopes of all elements prepared.

12- Fission

Fermi doing his uranium-238 to neptunium and plutonium realize energy released.
1939 – Hahn & Strassmen proved that whenever large energy released, atoms of intermediate atomic number produced.
Meitner (refugee from Hitler's Germany) suggested that U absorbed neutron & split into two roughly equal fragments.
Smaller masses of these fragments explain great release of energy

YYY. When U splits, 0.1% of mass converted to energy

Meitner tells Bohr (going to US)
Named process fission and tried it on Uranium

ZZZ. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n + energy$

AAAA. Since neutrons released, they would encounter other uranium-235 and their would be a growing chain reaction.

BBBB. Instantaneous release of enormous amounts of energy.

13- The Atomic Bomb

Need to isolate uranium-235

CCCC. Plutonium-239 also fissionable

For bomb to explode, need minimum quantity of fissionable material (critical mass)

DDDD. Otherwise too many neutrons leave the mass w/o striking the nuclei

Produces high temperatures, severe shock wave and gamma rays.

EEEE. Radiation Sickness and genetic damage

Part Three: Canada's Nuclear Industry

14- Nuclear Reactors

Fermi's Pile

All reactors have fuel, a moderator, a control and a cooling system.

Control rods of cadmium metal.

Moderator: A material which slows down neutrons in a nuclear reactor so that they can be more easily captured by the uranium-235 nuclei present.

15- Canada and Nuclear Chemistry

Made the ZEEP (Zero Energy Experimental Pile)

Used to find the best distances between fuel rods for various fuels.

FFFF. Varies for metallic uranium, uranium oxide and uranium carbide.

GGGG. Best distance depends on kind of metal container.

Heavy Water NRX Reactor

HHHH. Automatic means of irradiating elements for production of isotopes.

IIII. Creates many neutrons.

JJJJ. Place an element in the area of neutron bombardment and will get a radioactive isotope of the same or some other element.

KKKK. $$\underset{non-rad.}{{}^{59}_{27}Co} + {}^{1}_{0}n \rightarrow \underset{rad.}{{}^{60}_{27}Co}$$

No NRU best reactor for research. Cooled and moderated by heavy water (fueled with natural uranium)

16- AECL Power Projects

Design nuclear power plants

CANDU reactor in Douglas Point – 200MW

17- CANDU Reactors

Fuel

LLLL. UO_2 pellets are placed in zircaloy tubes (from Uranium Ore U_3O_8)

MMMM. Placed in a reactor vessel.

NNNN. 0.7% Uranium-235

OOOO. Two types of reaction take place

Uranium-235 Fissions: ${}^{235}_{92}U + {}^{1}_{0}n\,(slow) \rightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3{}^{1}_{0}n\,(fast) + Energy$

Neutrons absorbed by Uranium-238: ${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e$
$then\ {}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}e$

PPPP. Chain reaction because neutrons are created and used up.

Moderator

QQQQ. Need to slow the fast moving neutrons from 42 000 km/s to 3km/s in order for them to be absorbed by uranium-235 nuclei.

RRRR. To do this, must colloid with particles of similar mass: Heavy water effective at this.

Good because it does not absorb neutrons like graphite and light water.

Capturing fission neutrons would interfere with the chain reaction.

If use normal water, need 3-5% as opposed to 0.7% Uranium-235.

Controls

SSSS. Controls energy output

Increase/Decrease light water in the fuel channels of the calandria

1. More water, more neutrons absorbed, less energy
2. Vice-versa

Have different channels in the calandria and can slow parts down and speed parts up.

TTTT. Shut-down mechanisms

Shutoff rods: Neutron absorbing cadmium-stainless steel alloy rods dropped into calandria.

Inject liquid poison of concentrated gadolinium nitrate solution to absorb neutrons.

Dump heavy water into a special drop tank located below the calandria. The fast neutrons are not slowed enough for fission to continue.

Coolant

UUUU. Atoms in the fuel jostle and heat up.

VVVV. Heavy water is used as a coolant in CANDU (flows through tubes which enclose the fuel bundles)

WWWW. Under high pressure so as to not boil.

XXXX. Circulated to a steam generator, causing ordinary water to boil.

Steam fed to turbines, which drive electric generators.

YYYY. Heavy water goes back to reactor core.

Used Fuel

ZZZZ. Fuel bundles produce heat for 17 months.

AAAAA. 70% Uranium-235 used up.

BBBBB. Fuel bundle contains: 98.6 uranium-238, 0.2% uranium-235, 0.4% plutonium, and 0.8% of other isotopes.

CCCCC. After ten years, 99.8% radiation eliminated by natural decay in ten years.

DDDDD. Stored in think-walled reinforced concrete pools.

Water must be present for first few years.

Water cools and protects.

EEEEE. Permanent disposal (no one sure)

Seal in corrosion proof containers and dispose.

Or, extract useful plutonium and chemically react other waste with glass-forming substances to form insoluble solids for permanent disposal.

But in deep vault carved out of rock in the Canadian Shield (stable for millions of years)

18- Production of Heavy Water

In normal water 1/7000 molecules
Deuterium migrates to hydrogen sulfide at 128°C.

FFFFF. $D_2O_{(L)} + H_2S_{(g)} \rightarrow H_2O_{(L)} + D_2S_{(g)}$

The D_2S is then dissolved in cooler (32°C) water, and the deuterium migrates to the water, enriching its contents of D_2O:

GGGGG. $D_2S_{(g)} + H_2O_{(L)} \rightarrow D_2O_{(L)} + H_2S_{(g)}$

Repeat process until D_2O concentration at 20 to 30%.
D_2O boils at 101.4 (not 100.0 like H_2O)
Boil at 100.0°C…Yields reactor grade D_2O at 99.75% pure.

Section 2

P. 596: Part I Review Questions 1-5

1- Describe Rutherford's lead block experiment which showed that three different kinds of rays can be emitted from radioactive substances.

Rutherford put a radium salt in a hole in a block of lead and then placed a magnet in front of it and so that on a zinc sulphide screen, there were three charged patches of light (Alpha +, Gamma, Beta -).

2- Explain the meaning of the terms binding energy, p/n ratio, and even-odd rule. Show how they are involved in determining the relative stability of a nucleus.

Binding Energy: The energy produced when a nucleus is made from its components. (large binding energy = stable)
p/n Ratio: Number of protons to neutrons. Closer to 1:1 is more stable.
Even-odd Rule: Even protons / Even Neutrons most stable | Even/Odd more often unstable | Odd/Odd unstable (rarely stable)

3- Complete the following equations:

A. ${}^{27}_{13}Al + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + ?$

${}^{27}_{13}Al + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + {}^{29}_{12}Mg$??

B. ${}^{7}_{3}Li + ? \rightarrow 2{}^{4}_{2}He$

${}^{7}_{3}Li + {}^{1}_{1}H \rightarrow 2{}^{4}_{2}He$

4- What is the difference between nuclear fusion and nuclear fission?

Fusion: The process wherein two light nuclei combine to form a heavier, more stable nucleus.
Fission: The process wherein a heavy nucleus splits to form nuclei of intermediate mass.
Fusion is the process of combining, whereas fission is the process of splitting nuclei.

5- What is mean by the half-life of a radioactive substance? How can a knowledge of the half-life of a substance be used to determined the age of a material in which the substance is present?

Half-Life: The length of time required for half of the original number of nuclei in a radioactive sample to decay.
Can be used as carbon dating (find out how much as decayed by analyzing the percentage of decay products in the sample)

P. 602: Part II Review Questions 1-4

1- Write an equation for a reaction which involves the artificial transmutation of one element to another.

$^{7}_{3}Li + ^{1}_{1}H \rightarrow 2^{4}_{2}He + energy$

2- Why are neutrons better bullets for studying atomic nuclei than alpha particles or protons?

They do not have a charge as protons do and are hence not repelled by the nucleus (don't need to bombard the nucleus with particles at the same speed).

3- Describe in words a chain reaction such as the one that is involved in the fission of uranium nuclei.

The fission reaction of uranium nuclei is a chain reaction, as one neutron is needed to split a uranium-235 nuclei and the product of the reaction is 3 neutrons, energy, strontium and Xenon. Accordingly, the process may continue without human interference, as the 3 neutrons produced may continue fission with other uranium-235 nuclei (the process will continue).

4- What is mean by the critical mass of a fissionable material? Why is critical mass important?

Critical Mass: The minimum mass of fissionable material required for an explosive chain reaction.
Critical mass is an important concept as fission may not commence in an atomic bomb without such a mass of fissionable material. Moreover, it is critical to safety in such weapons, as the critical mass can be divided into two separate quantities that cannot react until they are put into contact with one another.

P. 612: Part III Review Questions 1-7

1- What are the three main functions of a nuclear reactor?

A. Produce radioactive isotopes.
B. Release vast amounts of energy in the form of heat from fission of small quantities of matter.
C. Produce new nuclear fuels from nonfissionable elements.

2- What is the fuel used in the CANDU reactor?

UO_2 Fuel pellets (0.7% uranium-235)

3- Write the equations for the chain-reaction fission of uranium-235 and for the neutron capture reactions of uranium-238.

Uranium-235 Fissions: $^{235}_{92}U + ^{1}_{0}n\ (slow) \rightarrow ^{90}_{38}Sr + ^{143}_{54}Xe + 3^{1}_{0}n\ (fast) + Energy$

Neutrons absorbed by Uranium-238: $^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$
$then\ ^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$

Plutonium-239 then undergoes fission.

4- Describe the function of a moderator. What is the moderator used in a CANDU reactor?

A material which slows down neutrons in a nuclear reactor so that they can be more easily captured by uranium-235 nuclei present.
Heavy Water (D_2O) is used in the CANDU reactor.

5- Describe briefly the three types of shut-down mechanisms used in a CANDU reactor.

D. Shutoff rods: Neutron absorbing cadmium-stainless steel alloy rods dropped into calandria.
E. Inject liquid poison of concentrated gadolinium nitrate solution to absorb neutrons.
F. Dump heavy water into a special drop tank located below the calandria. The fast neutrons are not slowed enough for fission to continue.

6- How is heavy water obtained from ordinary water?

G. In normal water 1/7000 molecules
H. Deuterium migrates to hydrogen sulfide at 128°C.

$$D_2O_{(L)} + H_2S_{(g)} \rightarrow H_2O_{(L)} + D_2S_{(g)}$$

I. The D_2S is then dissolved in cooler (32°C) water, and the deuterium migrates to the water, enriching its contents of D_2O:

$$D_2S_{(g)} + H_2O_{(L)} \rightarrow D_2O_{(L)} + H_2S_{(g)}$$

J. Repeat process until D_2O concentration at 20 to 30%.
K. D_2O boils at 101.4 (not 100.0 like H_2O)
L. Boil at 100.0°C…Yields reactor grade D_2O at 99.75% pure.

7- State four uses for radioactive isotopes.

M. Medical Therapy: Cobalt-60 for treating malignant tumours.
  1. Intense gamma rays.
  2. Cesium-137 also used
N. Gamma radiation from cobalt-60 used to sterilize vegetables, fruit and grain (medical supplies/wool)
O. Give fruits longer shelf lives.
P. Studying the wearing of machine parts.
Q. Can add to a pipeline to determine where a leak is.

Section 3

P. 618: Test Your Understanding Questions 1-15

1- Marie Curie suspected that pitchblend contained an element that was more radioactive than uranium because:

B) Pitchblend is more radioactive that Uranium.

2- The most highly radioactive element among the following is:
C) Ra (Radium)

3- Rutherford's lead block experiment showed that
A) Radium emits alpha, beta and gamma rays.

4- The energy that is released when a nucleus is made from the isolated protons and neutrons is called
D) Binding Energy

5- A nucleus is more likely to be stable when it has
A) An even number of protons and an even number of neutrons.

6- The question mark in the nuclear equation $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ?$
C) $^{4}_{2}He$

7- When two light nuclei combine to form a heavier more stable nucleus, the process is called
B) Fusion

8- Beta decay consists of the emission
B) An electron from a nucleus.

9- If the half-life of a radioactive element is 1 h, its level of radioactivity will have dropped 25% of its original value after a period of:
C) 2 h (Check this)

10- A device which allows a nuclear chain reaction to be controlled is called
B) A reactor (Check this)

11- The fuel for a CANDU reactor consists of
A) Pellets of UO_2

12- The large reaction vessel which contains the fuel bundles of a CANDU reactor is called a
C) Calandria

13- The rate of energy output from a reactor can be increased by
B) Removing some ordinary water from the liquid zone control units.

14- The nuclear fuel produced by a breeder reactor is
B) Plutonium-239

Section 4

P. 612: Review Your Understanding Questions 1-29

1- How does the presence of a radioactive substance affect a charged electroscope?

A. Discharges electroscope

HHHHH. Rays ionize the gas (air) in the electroscope by knocking off the outer electrons.

IIIII. The resulting charged ions are able to conduct electricity and the charge is removed.

2- What information regarding radioactivity was gained from Rutherford's lead block experiment?

That there are three types of radioactivity: Alpha particles (+), Beta Particles (-) and Gamma Rays (neutral).

3- How do alpha, beta and gamma rays differ from each other in their properties?

B. Positive Charge = Alpha
1. Helium Nuclei (2 protons / 2 neutrons)
2. Charge 2+
3. Mass 4u
4. Speed 0.05 Light
5. Weak penetrating power
    a) Range of few cm in air
    b) Stopped by thin sheets of aluminum or paper
6. Ionize gas molecules through which they pass

C. Negative Charge Beta
1. High-Energy electrons
2. Negative Charge
3. Speed 0.3 - 0.99 Light
4. Greater penetrating power
    a) Several millimeters of Aluminum
5. Do not ionize gas molecules as well as alpha particles

D. Uncharged = Gamma Rays
1. No charge
2. Not particles
3. High-energy, high-frequency electromagnetic radiations (similar to x-rays)
4. Speed = Light
5. Very penetrating
    a) 5 cm lead
    b) 30 cm Steel
6. Little ionizing effect on gases
7.

4- From what part of a radioactive atom do the alpha or beta particles come?

E. Alpha particles: Helium Nucleus → So they originate from nucleus

F. Beta Particles: Electrons → So they originate from the electron cloud.

5- Why is $^{35}_{15}P$ likely to be an unstable nucleus?

G. Not 1:1 p/v ratio
H. Odd number of protons.

6- Why is $^{18}_{9}F$ likely to be an unstable nucleus?

I. Odd number of protons.
???

7- Would you expect the following nuclei to be stable or unstable? State your reason in each case.

J. $^{3}_{1}H$

No, odd number of protons and a p/v ratio of 1:2.

K. $^{20}_{10}Ne$

Yes, even number of protons/neutrons and a 1:1 p/v ratio.

L. $^{58}_{29}Cu$

Unstable, because an odd number of protons and neutrons.

M. $^{210}_{83}Bi$

Unstable, because odd protons/neutrons and not a 1:1 p/v ratio.

8- What is the relationship between nuclear binding energy and the stability of a nucleus?

+++ Binding Energy, +++ Stable

9- Write the equation for the emission of an alpha particle from $^{266}_{88}Ra$.

$$^{266}_{88}Ra \rightarrow ^{262}_{86}Rn + ^{4}_{2}He$$

10- Write the equation for the emission of a beta particle from $^{214}_{82}Pb$.

$$^{214}_{82}Pb \rightarrow ^{0}_{-1}e + ^{214}_{83}Bi$$

11- Write the equation for successive emissions of an alpha particle and a beta particle from $^{214}_{84}Po$.

$$^{214}_{84}Po \rightarrow ^{210}_{82}Pb + ^{4}_{2}He$$
$$^{210}_{82}Pb \rightarrow ^{210}_{83}Bi + ^{0}_{-1}e$$
(check!)

12- What is meant by the half-life of a radioactive element?

Time for an atom to degenerate to ½ of its original number of nuclei.

13- The half-life of Fm-253 is 4.5 days. What fraction of 1 g of Fm would remain after 13.5 days?

???

14- Why are neutrons better particles for bombarding atomic nuclei than protons or alpha particles?

Because they have no charge and do not need to be fired at such a high speed as alpha particles.

15- What can happen when a neutron is fired at the nucleus of an atom?

The nucleus add to the mass of the atom, as it will remain in the atom's nucleus. Subsequently, the atoms nucleus can split into fragments, releasing immense amounts of energy (fission).

16- What is meant by the term *transmutation*?

A change in the identity of a nucleus because of a change in the number of protons in the nucleus.

17- What is a fission reaction?

The process wherein a heavy nucleus splits to form nuclei of intermediate mass.

18- What nucleus is left out of the follow equation?

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{147}_{59}\text{Pr} + ? + 3^{1}_{0}n$

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{147}_{59}\text{Pr} + ^{86}_{33}Rn + 3^{1}_{0}n$

19- Describe a chain reaction and state how the fission of $^{235}_{92}U$ can produce a chain reaction.

Chain Reaction: NUCLEAR PHYSICS **self-sustaining nuclear fission:** a self-sustaining nuclear reaction in which each fission of an atomic nucleus causes neutrons and energy to be emitted, each collision of neutrons with other nuclei causing a further fission

Uranium 235 can produce a chain reaction in the sense that upon fissioning 3 neutrons are released which will split the nucleus of other Uranium-235, which will produce more nuclei.

20- Describe the parts of a nuclear reactor and their functions. What are the main uses of a reactor?

N. Main Use: Power / Research

O. Refer to Notes on Part 3.

21- In the CANDU system, what happens when the heavy water moderator is released into the dump tank? Why?

When the heavy water moderator is released into the dump tank the reaction will cease, as the "fast neutrons are not slowed sufficiently for fission to continue."

22- What is a transuranium element?

The elements which have more than 92 protons.

23- For what purpose can cobalt-60 be used?

It can be used to treat malignant tumours.

24- What is the purpose of a breeder reactor?

The purpose of a breeder reactor is to produce fissionable plutonium-239 from uranium-235 by limiting the amount of moderators used. (fast neutrons released change uranium-238 into plutonium-239).

25- What type of nuclear reaction is the following?

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

? Artificial transmutation.

26- Complete the following nuclear equations:

P.
$^{31}_{15}P + ^{1}_{1}H \rightarrow ^{28}_{14}Si + ?$
$^{31}_{15}P + ^{1}_{1}H \rightarrow ^{28}_{14}Si + ^{4}_{2}He$

Q.
$^{27}_{13}Al + ^{4}_{2}He \rightarrow ? + ^{1}_{1}H$
$^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{14}Si + ^{1}_{1}H$

R.
$^{23}_{11}Na + ^{2}_{1}H \rightarrow ^{1}_{1}H + ?$
$^{23}_{11}Na + ^{2}_{1}H \rightarrow ^{1}_{1}H + ^{24}_{11}Na$

S.
$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{37}Rb + ^{144}_{55}Cs + 2^{1}_{0}n$
$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{37}Rb + ? + 2^{1}_{0}n$

T.
$^{3}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ?$
$^{3}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + 2^{1}_{0}n$

U.
$^{228}_{90}Th \rightarrow ^{4}_{2}He + ?$
$^{228}_{90}Th \rightarrow ^{4}_{2}He + ^{224}_{88}Ra$

V.
$^{12}_{5}B \rightarrow ^{0}_{-1}e + ?$
$^{12}_{5}B \rightarrow ^{0}_{-1}e + ^{12}_{6}C$

27- State which type of nuclear reaction is illustrated by each equation in question 26.

W. Alpha Decay
X. Artificial Transmutation
Y. Artificial Transmutation ??
Z. Fission
AA. Alpha Decay
BB. Alpha Decay
CC. Beta Decay

28- What is the half life of a radioactive isotope if 1.20mg of it decays to 0.30 mg in 40 minutes?

???

29- Describe how heavy water is produce for use in CANDU reactors.

DD. In normal water 1/7000 molecules

EE. Deuterium migrates to hydrogen sulfide at 128°C.

1. $D_2O_{(L)} + H_2S_{(g)} \rightarrow H_2O_{(L)} + D_2S_{(g)}$

FF. The D_2S is then dissolved in cooler (32°C) water, and the deuterium migrates to the water, enriching its contents of D_2O:

1. $D_2S_{(g)} + H_2O_{(L)} \rightarrow D_2O_{(L)} + H_2S_{(g)}$

GG. Repeat process until D_2O concentration at 20 to 30%.
D_2O boils at 101.4 (not 100.0 like H_2O)
Boil at 100.0°C…Yields reactor grade D_2O at 99.75% pure.

Part 2: General Chemistry – Harwood and Petrucci

Section 1

Read Chapter 7-9, pp 227-232

1. Fossil Fuels
   A. Derived from plant life
   B. CO_2 and H_2O converted to carbohydrates in presence of catalyst, chlorophyll
      1) $6CO_2 + 6H_2O \xrightarrow{\text{Chlorophyll \& Sunlight}} C_6H_{12}O_6 + 6O_2 \qquad \Delta H = +2.8 \times 10^3\,\text{kJ}$
   C. Higher heat of combustion, better fuel
2. Gasification of Coal
   A. Producer Gas (From Coal)
   B. P. 229
3. Liquefaction of Coal – P. 229
4. Methanol – CH_3OH – P. 230
5. Ethanol – C_2H_5OH – P. 231
6. Hydrogen – P. 231

Section 2

Pp 410-411: Semiconductors

1. Re-read this section
2. Semiconductor: A semiconductor is characterized by a small energy gap between a filled valence band and an empty conduction band.
3. For electrical conductivity: An energy band that is only partly filled with electrons.
4. Insulator must have valence band filled and a large energy gap between the valence band and the conduction band…Very few electrons are able to make the transition between the two.

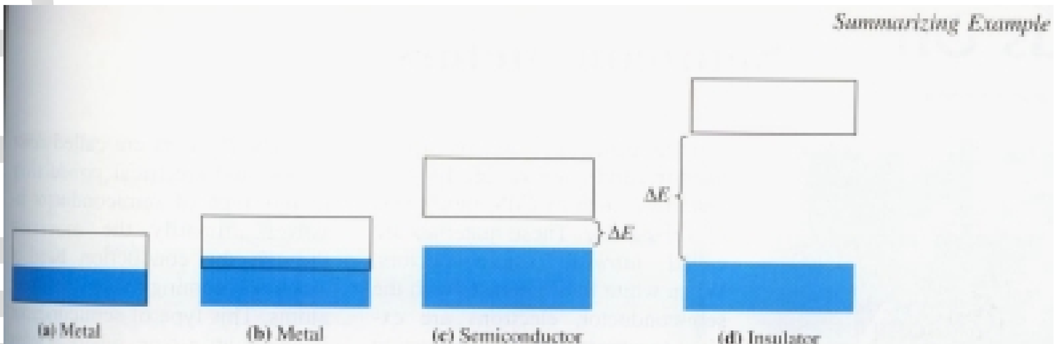

FIGURE 12-28 Metals, semiconductors, and insulators as viewed by band theory. (a) In some metals the valence band (blue) is only partially filled (e.g., the half-filled 3s band in Na). The valence band also serves as a conduction band (outlined in black). (b) In other metals the valence band is full, but a conduction band overlaps it (e.g., the empty 3p band of Mg overlaps the full 3s valence band). (c) In a semiconductor the valence band is full, and the conduction band is empty. The energy gap (ΔE) between the two is small enough, however, that some electrons make the transition between the two just by acquiring thermal energy. (d) In an insulator the valence band is filled with electrons, and a large energy gap (ΔE) separates the valence band from the conduction band. Few electrons can make the transition between bands, and the insulator does not conduct electricity.

5.

Pp 412-413: Semiconductors, Photovoltaic Cell

1. Re-read this section
2. If band gap fixed size – Intrinsic semiconductors
3. If size of band gap controlled by adding impurities (coping) – Extrinsic semiconductors

Section 3

Read Chapter 26, pp 897-903, pp 908-922

1- Alpha Particle

An alpha particle is a combination of two protons and two neutrons identical to the helium ion, that is, $^{4}He^{2}$. Alpha particles are emitted in some radioactive decay processes.

2- Beta Particle

A beta particle is an electron emitted as a result of the conversion of a neutron to a proton in certain atomic nuclei undergoing radioactive decay.

3- Control Rods

Control rods are neutron-absorbing metal rods (e.g., Cd) that are used to control the neutron flux in a nuclear reactor and thereby control the rate of the fission reaction.

4- Curie

A curie is a quantity of radioactive material producing 3.70×10^{10} disintegrations per second. (This is the decay rate for 1.00 g Ra.)

5- Decay Constant

A decay constant is a first-order rate constant describing radioactive decay.

6- Electron Capture (EC)

Electron Capture is a form of radioactive decay in which an electron from an inner electronic shell is absorbed by a nucleus. In the nucleus the electron is used to convert a proton to a neutron.

7- Fission

Nuclear fission is a radioactive decay process in which a heavy nucleus breaks up into two lighter nuclei and several neutrons accompanied by the released of energy.

8- Fusion

In nuclear fusion small atomic nuclei are fused into larger ones, with some of their mass being converted to energy.

9- Gamma Ray

Gamma rays are a form of electromagnetic radiation of high penetrating power emitted by certain radioactive nuclei.

10- Geiger-Müller (G-M) Counter

A Geiger-Muller counter is a device used to detect ionizing radiation. Ionizing event that occur in the counter produce electric discharges that can be recorded.

11- Half-Life

The half-life of a reaction is the time required for one-half of a reactant to be consumed. In a nuclear decay process, it is the time required for one-half of the atoms present in a sample to undergo radioactive decay.

12- Magic Numbers

Magic numbers is a term used to describe numbers of protons and neutrons that confer a special stability to an atomic nucleus.

13- Moderator

A moderator slows down energetic neutrons from a fission process so that they are able to induce additional fission.

14- Nuclear Binding Energy

Nuclear binding energy is the energy released when nucleons (protons and neutrons) are fused into an atomic nucleus. This energy replaces an equivalent quantity of matter.

15- Nuclear Equation

A nuclear equation represents the changes that occur during a nuclear process. The target nucleus and bombarding particle are represented on the left side of the equation, and the product nucleus and ejected particle on the right side.

16- Positron

A positron is a positive electron emitted as a result of the conversion of a proton to a neutron in a radioactive nucleus.

17- Rad

A rad is a quantity of radiation able to deposit 1×10^{-2} J of energy per kilogram of matter.

18- Radioactive Decay Law

The radioactive decay law states that the rate of decay of a radioactive material – the activity, A – is directly proportional to the number of atoms present.

19- Radioactive Decay Series

A radioactive decay series is a succession of individual steps whereby an initial radioactive isotope (e.g., ^{238}U) is ultimately converted to a stable isotope (e.g., ^{206}Pb)

20- Rem

A rem is a unit of radiation related to the rad, but taking into account the varying effects on biological matter of different types of radiation of the same energy.

Section 4

P. 924 : Questions 1-7, 15, 16, 23, 24

1- In your own words define the following symbols:

A. α : An alpha particle is a combination of two protons and two neutrons identical to the helium ion, that is, $^{4}He^{2}$. Alpha particles are emitted in some radioactive decay processes.

B. β^- : A beta particle is an electron emitted as a result of the conversion of a neutron to a proton in certain atomic nuclei undergoing radioactive decay.

C. β^+ : A positron is a positive electron emitted as a result of the conversion of a proton to a neutron in a radioactive nucleus.

D. $t_{1/2}$: The half-life of a reaction is the time required for one-half of a reactant to be consumed. In a nuclear decay process, it is the time required for one-half of the atoms present in a sample to undergo radioactive decay.

2- Briefly describe each of the following ideas, phenomena, or methods:

E. Radioactive decay series:

A radioactive decay series is a succession of individual steps whereby an initial radioactive isotope (e.g., ^{238}U) is ultimately converted to a stable isotope (e.g., ^{206}Pb)

F. Charged-particle accelerator:

Charged-particle accelerators are designed to accelerate particles to great speeds in order to created collisions between various particles, creating different types of matter (P. 903)

G. Neutron-to-proton ratio:

The neutron-to-proton ratio is often a reflection of the stability of a nucleus. Specifically, when Z is less than or equal to 20, a stable nucleus is given by a 1:1 ratio. In contrast, above this point, a larger number of neutrons are required (up to 1.5 : 1 for Bismuth, the last stable element at Z=83).

H. Mass-energy relationship:

This relationship is given by $E=mc^2$.

The issue with this statement is that mass is often loss in nuclear reactions (Mass Defect) and is converted to energy according to Einstein's equations.

I. Background radiation.

This is the amount of naturally occurring ionizing radiation that all life exists against – Cosmic rays, ultraviolet and emanations from radioactive element such as uranium in rocks. "The level of this radiation varies from point to point on Earth, being greater, for instance, at higher elevations. Only in recent times have humans beings been able to create situations in which living organisms might be exposed to radiation at levels significantly higher than natural background radiation."

3- Explain the important distinctions between each pair of terms:

J. Electron and positron

An electron is negative, whereas a positron is positive.

K. Half-life and decay constant

Half-life is the time it takes for half of the atoms of a given sample to undergo radioactive decay. In contrast, the decay constant is the first-order rate constant describing radioactive decay.

L. Mass defect and nuclear binding energy

Mass Defect: The mass converted into energy when a nucleus is made from its components

Binding Energy: The energy produced when a nucleus is made from its components

Clearly, the difference is in the fact that mass defect refers to the mass converted into energy, whereas binding energy refers to the energy produced.

M. Nuclear fission and nuclear fusion

Nuclear fission is based on the splitting of atoms (Energy released when atoms split) , whereas fusion is based on the creation of larger atoms from smaller ones (Mass converted to energy).

N. Primary and secondary ionization.

Primary ionization occurs when an α particle ionizes one atom. A secondary ionization differs in the sense that it is caused by an electron removed from the atom that was initially ionized who ionizes another atom.

Re-read page 917.

4- Which of the following – α, β, or γ – generally has the greatest

O. Penetrating power through matter?

γ

P. Ionizing power in matter?

α

Q. Deflection in a magnetic field?

β

5- Supply the missing information in each of the following nuclear equations representing a radioactive decay process.

R.
$${}^{160}_{?}W \rightarrow {}^{?}_{?}Hf + ?$$
$${}^{160}_{74}W \rightarrow {}^{156}_{72}Hf + {}^{4}_{2}He$$

S.
$${}^{38}_{?}Cl \rightarrow {}^{?}_{?}Ar + ?$$
$${}^{38}_{17}Cl \rightarrow {}^{38}_{18}Ar + {}^{0}_{-1}\beta^{-}$$

T.
$${}^{214}_{?}? \rightarrow {}^{?}_{?}Po + {}^{0}_{-1}\beta^{-}$$
$${}^{214}_{83}Bi \rightarrow {}^{214}_{84}Po + {}^{0}_{-1}\beta^{-}$$

U.
$${}^{32}_{17}Cl \rightarrow {}^{?}_{16}? + ?$$
$${}^{32}_{17}Cl \rightarrow {}^{?}_{16}S + {}^{0}_{+1}\beta$$

6- Complete the following nuclear equations.

V.
$${}^{23}_{11}Na + ? \rightarrow {}^{24}_{11}Na + {}^{1}_{1}H$$
$${}^{23}_{11}Na + {}^{2}_{1}H \rightarrow {}^{24}_{11}Na + {}^{1}_{1}H$$

W.
$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{56}_{25}Mn + ?$
$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{56}_{25}Mn + ^{4}_{2}He$

X.
$? + ^{2}_{1}H \rightarrow ^{240}_{94}Pu + ^{0}_{-1}\beta$
$^{238}_{92}U + ^{2}_{1}H \rightarrow ^{240}_{94}Pu + ^{0}_{-1}\beta$

Y.
$^{246}_{96}Cm + ? \rightarrow ^{254}_{102}No + 6^{1}_{0}n$
$^{246}_{96}Cm + ^{13}_{8}O \rightarrow ^{254}_{102}No + 5^{1}_{0}n$

Z.
$^{238}_{92}U + ? \rightarrow ^{246}_{99}Es + 6^{1}_{0}n$
$^{238}_{92}U + ^{14}_{7}N \rightarrow ^{246}_{99}Es + 6^{1}_{0}n$

7- Write nuclear equations to represent

AA. The decay of ^{214}Ra by α-particle emission;

$^{214}_{88}Ra \rightarrow ^{210}_{86}Rn + ^{4}_{2}He$

BB. The decay of ^{205}At by positron emission;

$^{205}_{85}At \rightarrow ^{205}_{84}Po + ^{0}_{+1}\beta$

CC. The decay of ^{212}Fr by electron capture;

$^{212}_{87}Fr + ^{0}_{-1}e \rightarrow ^{212}_{86}Rn$

DD. The reaction of two deuterium nuclei (deuterons) to produce a nucleus of ^{3}He;

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

EE. The production of $^{243}_{97}Bk$ by the α-particle bombardment of $^{241}_{95}Am$.

$^{241}_{95}Am + ^{4}_{2}He \rightarrow ^{243}_{97}Bk + 2^{1}_{0}n$

15- What is the nucleus obtained in each process?

A.
$^{234}_{94}Pu$ decays by α emission.
$^{234}_{94}Pu \rightarrow ^{4}_{2}He + ^{230}_{92}U$

B.
$^{248}_{97}Bk$ decays by β^- emission.
$^{248}_{97}Bk \rightarrow ^{0}_{-1}\beta^- + ^{248}_{98}Cf$

C.
$^{196}_{82}Pb$ goes through two successive EC processes.
$^{196}_{82}Pb + ^{0}_{-1}e \rightarrow ^{196}_{81}Tl$
$^{196}_{81}Tl + ^{0}_{-1}e \rightarrow ^{196}_{80}Hg$

16- What is the nucleus obtained in each process?

D.
$^{214}_{82}Pb$ decays through two successive β^- emissions.
$^{214}_{82}Pb \rightarrow ^{0}_{-1}\beta^- + ^{214}_{83}Bi$
$^{214}_{83}Bi \rightarrow ^{0}_{-1}\beta^- + ^{214}_{84}Po$

E. $^{226}_{88}$Ra decays through three successive α emissions.

$^{226}_{88}Ra \rightarrow ^{4}_{2}He + ^{222}_{86}Rn$

$^{222}_{86}Rn \rightarrow ^{4}_{2}He + ^{218}_{84}Po$

$^{218}_{84}Po \rightarrow ^{4}_{2}He + ^{214}_{82}Pb$

F. $^{69}_{33}$As decays by β^{+} emission.

$^{69}_{33}As \rightarrow ^{0}_{+1}\beta^{+} + ^{69}_{32}Ge$

23- Write equations for the following nuclear reactions.

A. Bombardment by ^{7}Li with protons to produce ^{8}Be and γ rays.

$^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{8}_{4}Be + \lambda$

B. Bombardment of ^{9}Be with $^{2}_{1}$H to produce ^{10}B.

$^{9}_{4}Be + ^{2}_{1}H \rightarrow ^{10}_{5}B + ^{1}_{0}n$

C. Bombardment of ^{14}N with neutrons to produce ^{14}C.

$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{14}_{6}C + ^{1}_{1}H$

24- Write equations for the following nuclear reactions.

D. Bombardment of ^{238}U with α particles to produce ^{239}Pu.

$^{238}_{92}U + ^{4}_{2}He \rightarrow ^{239}_{94}Pu + 3^{1}_{0}n$

E. Bombardment of tritium with $^{2}_{1}$H to produce ^{4}He.

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

F. Bombardment of ^{33}S with neutrons to produce ^{33}P.

$^{33}_{16}S + ^{1}_{0}n \rightarrow ^{33}_{15}P + ^{1}_{1}H$