Work Sheet 13
Some question to ponder about nuclear chemistry

1.
A person goes to get radiation treatment for cancer utilizing "brachytherapy" in which a small radioactive source is placed directly into the body.

The radiation center has some newly created radioactive sources of ^{192}Ir. They start out as 10 Curie sources. Under computer control and robot inserts the source using a long needle into the patient's body and holds it there for the treatment. When the source is new, the treatment can be as short as say 30 minutes.

Given that the half-life of ^{192}Ir is 74 days, what would be the intensity of the source that was originally 10 Curies after 3 months? How much longer would a radiation treatment take to achieve the same exposure of radiation for the patient?

$$^{192}Ir\ half\ life = t_{1/2} = 74\, days$$

$$k = decay\, constant = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{74\, days} = 9.365 \times 10^{-3}\, days^{-1}$$

First order kinetics:

$$A\,(90\, days) = A_0 \exp[-kt] = 10\ Curies * \exp[-9.365 \times 10^{-3}\, days^{-1} \bullet 90\, days]$$

$$A\,(90\, days) = 4.3\ Curies$$

For the patient to recieve the same amount of radiation from a 4.3 *Curie source, it would take*:

$$\frac{30 \min * 10\, Curie}{4.3\, Curie} = 70 \min$$

To understand the complexity of computing the exposure to a particular source, look at the typical decay of ^{192}Ir which is chosen in part for its simplicity.
http://ozradonc.wikidot.com/iridium-192

2. Why are many forms of nuclear decay also accompanied by the gamma radiation?
Often the nuclei formed directly after nuclear decay are not in their ground nuclear state, so a high energy photon (gamma ray) is emitted; as a result the newly formed nucleus is in an energetically more stable state.

3. You are standing 10 feet away from three different radioactive sources.

All three happen to be 1 Curie sources. The first is primarily an alpha emitter, the second a beta, and the third both a beta and gamma source. Will your exposure be the same or different for these three. If different from which will your exposure yield the highest exposure as measured in Sieverts?

4. Which will give you a higher exposure in Sieverts: holding a 10 microCurie alpha emitter in your hand, or breathing in a 10 microCurie alpha emitter into your lungs? Or will they both be the same since you are essentially absorbing all the radiation that is emitted?

A Sievert is a unit of measure that quantifies the biological effect of ionizing radiation. Holding an alpha emitter is not typically dangerous, since large Helium nuclei can be effectively shielded from human tissue by a layer of dead skin. Inhalation and ingestion of alpha particles, however, can amount to a serious dose of radiation that could damage one's cells. Breathing in an alpha emitter would result in a higher, potentially life-threatening radiation dose, and a higher exposure as measured in Sieverts.

More practice with balancing and decay products

Balance the following

$^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$

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

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

$^{212}_{83}Bi \rightarrow ^{4}_{2}He + ^{208}_{81}Tl$

The following nuclei decay via electron capture predict their decay product

$^{57}Co + ^{0}_{-1}\beta \rightarrow ^{57}_{26}Fe$

$^{68}Ge + ^{0}_{-1}\beta \rightarrow ^{68}_{31}Ga$

$^{49}V + ^{0}_{-1}\beta \rightarrow ^{49}_{22}Ti$

The following undergo alpha emission, predict their decay product

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

$^{238}U \rightarrow ^{232}_{90}Th + ^{4}_{2}\alpha$

$^{218}Rn \rightarrow ^{214}_{84}Po + ^{4}_{2}\alpha$

The following undergo beta decay, predict their decay product

$^{218}Po \rightarrow ^{218}_{85}At + ^{0}_{-1}\beta$

$^{90}Sr \rightarrow ^{90}_{39}Y + ^{0}_{-1}\beta$

$^{63}Ni \rightarrow ^{63}_{29}Cu + ^{0}_{-1}\beta$

When we speak of dangerous radiation exposure, are we customarily speaking of alpha radiation, beta radiation or gamma radiation? Discuss.
Gamma radiation exposure is customarily considered the most dangerous type of radiation. Gamma rays are a type of ionizing radiation, and can penetrate through the skin (and even go all the way through a human body); gamma rays are high-energy photons that can damage DNA and cells without killing them, which can lead to replication of altered cells.

Beta particles, which are also ionizing particles, have shorter mean free paths and are less penetrating than gamma rays, so they are considered less dangerous than gamma rays.

Alpha emitters, which are strong ionizing agents, will only do substantial harm if they are inhaled/ingested/intravenously introduced into the human body, so avoiding alpha radiation exposure is not a concern since they cannot penetrate human tissue.

People who work around radioactivity wear film badges to monitor the amount of radiation that reaches their bodies. These badges consist of small pieces of photographic film enclosed in a light-proof wrapper. What kind of radiation do these devices monitor?

Dosimeters can be used to monitor gamma rays, X-rays, neutrons, beta particles, etc. -- it really depends on the type purchased. The most common types, though, monitor gamma and X-ray radiation.

A sample of a particular radioisotope is placed near a Geiger counter, which is observed to register 260 counts per minute. Six hour later, the detector counts at a rate of 20 counts per minute. What is the half-life of the material?

$$\ln[A] = \ln[A]_0 - kt$$

$$\ln[20] = \ln[260] - k(360\,\text{min})$$

$$k = \frac{\ln[20] - \ln[260]}{-360\text{ min}} = 7.124 \times 10^{-3}\text{ min}^{-1}$$

$$t_{1/2} = \frac{\ln 2}{k} = t_{1/2} = \frac{\ln 2}{7.124 \times 10^{-3}\text{ min}^{-1}} = 97\text{ min}$$

In what way is the emission of gamma radiation from a nucleus similar to the emission of light from an atom?

A nucleus in an excited state may emit one or more photons of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus, but moves the nucleus from a higher to a lower energy state (unstable to stable). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

Atomic emission is a process wherein an atom that has been excited (via heat, light, etc) to a discrete high-energy state converts to a lower energy state via emission of a photon (whose energy corresponds to the difference between the excited and ground electronic states of the atom). Often, the photon has an energy (or wavelength) that is in the visible region of the electromagnetic spectrum (visible to human eyes; one common example is the light emitted from Neon signs).

In both cases (nuclear relaxation and atomic emission), the result of the photon being emitted is a lower energy, more stable state for the atom.

Can it be truthfully said that, whenever a nucleus emits an alpha or beta particle, it actually becomes the nucleus of a different element?

When a nucleus emits an alpha particle (a He nucleus), the number of protons the initial nucleus contained is altered, which creates an atom with a different atomic number, meaning an atom of a different element is the result.
When a nucleus emits a beta particle, a neutron is actually being converted to an electron and a proton, and the electron is being emitted. This also creates an atom with a different number of protons (a new atomic number), leading to the production of an atom of a different chemical element.