Please read the problems carefully and answer them in the space provided. Write on the back of the page, if necessary. Show your work where requested in order to be considered for partial credit. In problems where you are requested to show your work, no credit will be given unless your work is shown.

Potentially useful formulas:

F = \frac{G m_1 m_2}{r^2}
F = \frac{k q_1 q_2}{r^2}
F = ma

Distance = Speed \times Time
v = \frac{\Delta x}{\Delta t}
a = \frac{\Delta v}{\Delta t}

Momentum = p = mv

Length contraction (space is longer in proper frame) : L' = \gamma L
Space dilation (time is shorter in proper frame) : T = \gamma T'

\gamma = \frac{1}{\sqrt{1 - (\frac{v}{c})^2}}

Wave properties : v = \lambda f ; f = 1/T (T = period)

Energy of a particle/wave : E = hf
De Broglie matter waves : \lambda = \frac{h}{p} = \frac{h}{mv}

Uncertainty principle : \Delta x \Delta p > h ; \Delta E \Delta t > h

Constants : c = 300,000 \times 10^3 \text{ m/s} ; G = 6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2}
k = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2} ; h = 6.6 \times 10^{-34} \text{ Js}

Do not forget to put units in your results!

(6 pts) 1. Light is emitted from atoms when an electron is
   (a) boosted to a higher energy level
   (b) makes a transition to a lower energy level
   (c) in a circular orbit around the nucleus
   (d) in an orbital
   (e) absorbed into the nucleus

   6 pts

(6 pts) 2. Which of the following is fundamentally different from the others? Explain why.
   (a) X-rays
   (b) light waves
   (c) radio waves
   (d) sounds waves
   (e) gamma rays

   All others are different types of electromagnetic waves.

   12 pts
3. True or False. One point each. No justification needed.

(a) A chain reaction refers to the chemical processes that occur for example when hydrogen and oxygen are mixed and heated with a flame  

(b) The size of the atomic nucleus is approximately 100 times smaller than the atom itself

(c) A subcritical mass of $^{239}$Pu can be made supercritical by compressing it with explosives, causing the nuclear detonation

(d) Radioactive decays are a good example of the wavelike nature of microscopic particles

(e) According to Heisenberg’s uncertainty principle, a baseball has a smaller range of possibilities (quantum uncertainty) than an electron

(f) If Planck’s constant $h$ was smaller, atoms would be smaller because quantum uncertainties would be smaller

(g) The fact that individual dots seen on a photographic plate when a photo is taken at extremely short exposure times is evidence that light is made of waves

(h) In a double-slit experiment with light the impact point of each photon cannot be predicted, and neither can the overall pattern of impact points

(i) Nuclear fission is the energy source that powers stars

(j) Evidence that the solar system is around 4.5 billion years old comes from the radioactive decays of rocks from Earth, the Moon and meteorites.

4. When we say that an electromagnetic field is “quantized”, we mean that

(a) whenever it interacts with atoms, it must deposit an entire “quantum” of energy at each interaction

(b) it impacts a viewing screen as tiny bundles of radiation

(c) its energy is “digitized” to have either 0, 1, 2, 3, etc. units of a basic energy increment

(d) all of the above

(e) none of the above

5. Other than radioactive decay, how can energy be released from the nucleus?

(a) nuclear fusion

(b) nuclear fission

(c) both of the above

(d) thermal decay

(e) all of the above
6. The following figure is the spectrum obtained from light from the Sun. It has two distinct components: a continuum and dark lines. Explain how they are formed and what they tell us about the composition of the Sun.

THE SUN IS A MASSIVE BALL OF HOT GAS. GAS AT THAT TEMPERATURE AND DENSITY EMITS LIGHT AT ALL WAVELENGTHS (THAT’S THE CONTINUUM RAINBOW-LIKE COMPONENT) FOLLOWING A BLACK-BODY SPECTRUM DISTRIBUTION OF INTENSITY AS A FUNCTION OF λ. IN THE CASE OF THE SUN THE MAXIMUM INTENSITY IS AROUND THE YELLOW λ. THAT CONTINUUM SPECTRUM IS WHAT WE SEE WHEN WE MAKE SUNLIGHT PASS THROUGH A PRISM.

THE DARK "ABSORPTION" LINES COME FROM ATOMS IN THE OUTER (AND COLDER) ATMOSPHERE OF THE SUN. THE ELECTRONS IN THESE ATOMS ABSORB LIGHT AT SPECIFIC WAVELENGTHS AND ARE EXCITED TO HIGHER ORBITALS, CREATING "HOLES" IN THE WAVELENGTHS THAT EMERGE FROM THE ATMOSPHERE. THESE ABSORPTION LINES ARE SEEN AT THE SAME WAVELENGTHS WHERE EMISSION LINES WOULD BE SEEN IF THE GAS WAS EMITTING LIGHT INSTEAD OF ABSORBING IT. THE POSITION OF THE LINES IS SPECIFIC TO EACH ELEMENT PRESENT IN THE SUN’S ATMOSPHERE, SO WE USE THEM AS UNIQUE FINGERPRINTS OF THE SUN COMPOSITION.

7. Regarding the electric charges of the electron, proton and neutron:

(a) the proton has a positive charge, the neutron has a negative charge whose strength is equal to that of the proton’s charge, and the electron has no charge

(b) the proton has a positive charge, the electron has a much smaller negative charge, and the neutron has no charge

(d) these objects are charged only when they reside in an ionized atom; otherwise all three are uncharged

(e) the electron has a negative charge, the proton has a positive charge, and the neutron has a charge that can be positive or negative or zero depending on the ionization of the atom in which it resides
(12 pts) 8. An important use of the artificially created isotope of strontium $^{89}\text{Sr}$ is to cure bone cancer, as it attaches itself to the bone and kills the metastasis growth. It is a $\beta^-$ emitter, and these electrons are more effectively absorbed by the metastasis than by healthy bone (by a factor greater than 10 to 1), so it is also relatively harmless.

(a) (3 pts) What is the atomic number and atomic mass of the byproduct of the beta decay of $^{89}\text{Sr}$?

$$^{89}\text{Sr} \longrightarrow ^{89}X + e^- + \overline{\nu_e}$$

where $X$ is the element yttrium. In $\beta$ decay a neutron is transformed into a proton: equal $A + 2 + 1$

(b) (3 pts) If we bombard $^{89}\text{Sr}$ with alpha particles, what is the atomic number and atomic mass of the resulting element?

$$^{89}\text{Sr} + 2\alpha \longrightarrow ^{93}X$$

where $X$ is the element zirconium. $\alpha$ particles are nuclei of helium, so $A + 4$, $2 + 2$

(c) (6 pts) $^{89}\text{Sr}$ has a half-life of 50 days. If a sample of this isotope is injected in a patient today with an activity of 1000 decays per second, how long will it take for the activity to drop to 125 decays per second?

$$t_{1/2} = 50 \text{ days}$$

$$\begin{array}{|c|c|c|}
\hline
\text{ACTIVITY} & \frac{dN}{dt} & \text{days} \\
\hline
1000 & 0 & 3 \text{ half-lifes} : 150 \text{ days} \\
500 & 50 & \\
250 & 125 & \\
125 & 180 & \\
125 & 150 & \\
\hline
\end{array}$$

(12 pts) 9. Describe the formation of a star like our Sun and what processes make it stable.

NEW STARS ARE BORN FROM LARGE COLD GAS CLOUDS OF HYDROGEN AND HELIUM AND VERY SMALL TRACES OF OTHER ELEMENTS.

THE CLOUD WILL BEGIN TO CONTRACT DUE TO GRAVITY. AS IT CONTRACTS, THE GAS GETS HOTTER AND HOTTER. EVENTUALLY, THE CLOUD SHRINKS ENOUGH THAT ITS TEMPERATURE AND DENSITY ARE HIGH ENOUGH TO START THE NUCLEAR FUSION OF HYDROGEN INTO HELIUM. FOUR HYDROGEN NUCLEI ARE FUSED TOGETHER TO FORM ONE NUCLEUS OF HELIUM RELEASING A LOT OF ENERGY IN THE FORM OF PHOTONS (LIGHT) AND NEUTRINOS. THIS ENERGY FROM FUSION PRODUCES ENOUGH OUTWARD PRESSURE TO STOP THE INWARD FORCE OF GRAVITY.

ONCE THIS PROCESS STARTS THE STAR BECOMES STABLE AND CONTINUES BURNING HYDROGEN IN ITS CORE.
10. The source of energy for the creation of most gold atoms (a gold atom is heavier than an iron atom) used in jewelry is:
   (a) the gravitational collapse of a star
   (b) a goldsmith’s smelter
   (c) the fission of a heavier element such as radium or hafnium
   (d) the heat at the center of the Earth
   (e) the shock wave of a supernova explosion at the end of the life cycle for a large star

11. The fission reaction involves
   (a) the combining of two low-mass nuclei
   (b) the splitting of a large molecule into smaller molecules
   (c) the splitting of a light nucleus
   (d) the combining of two lighter molecules into a heavier molecule
   (e) the splitting of a heavy nucleus

12. Explain the different effects on the human body of the alpha, beta and gamma radiations.

   **Alpha radiation** is the most ionizing (because it has the largest electric charge and is the heaviest), so it is potentially the most dangerous. But it can be stopped easily in a few meters of air or a sheet of paper. If ingested though, it will cause lots of tissue damage as tissue atoms are torn apart by α particles.

   **Beta radiation** (electrons) is not as ionizing as alpha, so it is safer. But it can still produce damage because it can penetrate further than alpha. So you have to move further away from it or put a thin lead shield. If a substance is breathed in or swallowed it will produce damage. Some β emitters are used to treat cancer, as cells dividing rapidly (like cancer cells) are more affected by radiation.

   **Gamma rays** are very energetic electromagnetic radiation (light). They are weakly ionizing, they can rip atoms apart but don’t do it very often. So they propagate the furthest; around 10 cm of lead are needed to stop them. In weak doses, they pass straight through living cells without interacting, so they can be used in medical imaging.