Name _____________________________

Each problem is worth 10 points.

**Constants**
- speed of light: \( c = 3 \times 10^8 \text{ m/s} \)
- parsec: \( 1 \text{ pc} = 3.26 \text{ ly} = 3.1 \times 10^{16} \text{ m} \)
- electron-volt: \( 1 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \)
- Plank constant: \( h = 6.6 \times 10^{-34} \text{ J/Hz} \)
  - \( hc = 1240 \text{ eV nm} \)
  - \( \hbar c = 197.3 \text{ eV nm} \)
- Fine structure constant: \( \alpha = \frac{1}{137} = \frac{v}{c} \) of electron in H ground state
- Hubble constant: \( H_0 = 74 \text{ km/s per Mpc} \)
- electron mass: \( mc^2 = 511.00 \text{ keV} \)
- proton mass: \( mc^2 = 938.272 \text{ MeV} \)
- neutron mass: \( mc^2 = 939.565 \text{ MeV} \)
- deuteron mass: \( mc^2 = 1875.613 \text{ MeV} \)

**Equations**
- Lorentz factor: \( \gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \)
- time dilation: \( t' = \gamma t \)
- length contraction: \( l' = l/\gamma \)
- Einstein relation: \( E^2 = (pc)^2 + (mc^2)^2 \)
- Hubble law: \( v = H_0 D \)
- Planck law: \( E = hf = \frac{hc}{\lambda} \)
- de Broglie wavelength: \( \lambda = \frac{h}{p} \)
- Uncertainty principle: \( \Delta x \Delta p \geq \frac{h}{4\pi} = \frac{h}{2} \)
  - \( \Delta E \Delta t \geq \frac{\hbar}{2} \)
- Planck scale: \( m = 2.2 \times 10^{-8} \text{ kg} \)
  - \( l = 1.6 \times 10^{-35} \text{ m} \)
  - \( q = 1.9 \times 10^{-18} \text{ C} \)
1. A muon is created in the atmosphere from a cosmic ray interaction, and travels at speed $2.8 \times 10^8$ m/s. It decays after traveling a distance measured by us to be 5000 m. (a) Calculate the lifetime of this muon as we measure it. (b) Calculate the lifetime of this muon in its rest frame.

2. Calculate the energy released when a proton and neutron fused into a deuteron (deuterium nucleus) during the Big Bang.

3. Einstein Rings occur when a galaxy lines up directly behind a massive object, such as another galaxy, as viewed from Earth. Draw a diagram showing why Einstein Rings are observed.

4. The galaxy UDFy-38135539 is one of the most distant seen to date, at a distance of 13.1 billion light-years estimated from redshift measurements. (a) Calculate the speed at which this galaxy recedes from us. (b) If the universe is 13.7 billion years old, determine the age of the universe when light that we see from this galaxy was emitted.

5. What fraction of the universe's matter/energy is thought to be in the form of dark matter? What fraction is thought to be in the form of dark energy?

6. The alkali element cesium is a popular photoemitter due to its low ionization energy, 2.14 eV. Calculate the maximum wavelength of light that will knock an electron out of Cesium. In which region of the spectrum (UV, visible, IR) is this wavelength?

7. The quartz crystal has a characteristic spacing of 0.4193 nm. (a) Calculate the energy of electrons with matching wavelength (a good choice for electron diffraction). (b) Calculate the energy of photons with matching wavelength (a good choice for x-ray diffraction).

8. The uncertainty of the position of the electron in the ground state of H is roughly equal to the diameter of the atom, 0.1 nm. (a) Calculate the uncertainty in the electron's momentum. (b) How does this compare to the momentum of the electron?

9. Why is high temperature required to make a magnetic confinement fusion reactor feasible?

10. List two sources of neutrinos that are detected in the IceCube neutrino observatory.