Astronomy 2020 **Fall 2020**
Homework #1 Due: Sep. 9

Answers to these homework problems will be submitted as hardcopy at the beginning of class on the due date or electronically as a PDF sent via E-mail to Professor Burns by 5 pm on the due date.

1. (5 pts). Let's deconstruct the article that you were given as a homework reading "The elusive why of space exploration". The article claims that we rarely ask why we explore but instead focus more on the tools of exploration. Argue why you think it is or is not important to concentrate on the why. Also, do you agree that the public and the Congress will invest in space by being inspired or aspirational? If not, what justifies the billions in expenditures for NASA?

The "why" question is at the heart of the justification for any organization to exist. Why does Apple or General Motors exist, and why does NASA exist? Apple produces iPhones and General Motors produces cars but that's the product not the reason they exist. Similarly, NASA launches rockets but why does it exist? NASA can go where no one else goes – to orbit the Earth, to the Moon, and Mars. It explores the great questions about the future of Earth, the origin of life, and the future of humankind. These are the great questions and ones for inspiration. But, is this more important than generating a return on investment for taxpayers or creating new companies? Inspiring the next generation to reach higher ultimately impacts the human race and its progress.

In questions 2-5 below, choose the best answer. Then **explain** your reasoning in a few complete sentences. Each question is worth **2 points**.

2. Which of the following statements is *not* one of Newton's laws of motion?
   a. What goes up must come down.
   b. The rate of change of momentum of an object is equal to the net force applied to the object.
   c. In the absence of a net force, an object moves with constant velocity.
   d. For any force, there always is an equal and opposite reaction force.
   e. All of the above are Newton's laws of motion.

a is really a statement of Newton's Law of Gravity, but not the Laws of Motion. When you toss a ball into the air, gravity exerts a central force that decelerates the ball, eventually causing it to halt its upward motion, and then accelerates downward. b, c, and d are the 3 laws of motion that we studied in class.

3. How does the Space Shuttle take off?
   a. Its rocket engines push against the launch pad propelling the shuttle upwards.
   b. It converts mass-energy to kinetic energy.
   c. It achieves lift from its wings in the same way that airplanes do.
   d. Hot gas shoots out from the rocket and, by conservation of momentum, the shuttle moves in the opposite direction.
   e. The hot rocket exhaust expands the air beneath the shuttle, propelling it forward.

Newton's third law (action-reaction) is a statement of Conservation of Momentum and the reason that rockets work in space and on the ground. *a* cannot be correct because rockets work in free space where they have nothing to push against. *b* is incorrect because the Space Shuttle used a chemical propulsion in which chemical energy is converted into kinetic energy with much less efficiency than a direct conversion of mass into energy via Einstein $E=mc^2$. There is no air in space so there is nothing to provide lift on wings, thus *c* is incorrect. *e* is wrong because it is a version of *a* in which something pushes against something else which does not work in free space.

4. If you drop a rock from a great height, about how fast will it be falling after 5 seconds, neglecting air resistance?
    a. It depends on how heavy it is.
    b. It depends on what shape it is.
    c. 10 m/s
    d. 15 m/s
    e. 50 m/s

$V=a\times t$, where V= velocity, a = acceleration (10 m/s^2 near the Earth's surface), and *t* is time. So, after 5 seconds, the rock is moving at 50 m/s.

5. If an astronaut goes on a space walk outside the Space Station, she will quickly float away from the station unless she has a tether holding her to the station.
    a. true
    b. false

Newton's Law of Inertia says that this statement must be false. There must be a force exerted on a one object to cause it to accelerate away from another. So, an astronaut stepping out of the Space Station will be moving with the same momentum as the space station. The astronaut will move along with the Station and not float away unless the astronaut has a backpack with jets to change their momentum.

6. (6 pts). The escape velocity from the Moon is about 2400 m/sec.
    a. Using the rocket equation derived in class with a rocket exhaust velocity of 4500 m/sec, calculate the mass fraction of a rocket (ratio of mass in fuel to total mass of rocket + fuel) needed for it to leave the surface of the Moon.

$$M_f = \text{mass fraction} = \frac{\Delta m}{m+\Delta m} = 1\text{-}e^{-\Delta v/v_e}$$

Δv is the escape velocity from the Moon, while v_e is the exhaust velocity of the rocket. Substituting these into the above equation, we get

$$M_f = 1\text{-}e^{-2400/4500} = 0.41$$

This means that 41% of the total mass of the rocket must be dedicated to fuel. The rest of the mass is the rocket plus the payload.

b. Compare this to the mass fraction required to leave Earth where the escape velocity is 11,200 m/sec.

$$M_f = 1 - e^{-11,200/4500} = 0.92,$$

Or, 92% of the rocket must be dedicated to fuel! The stronger gravity of the Earth means that it takes more fuel to get off the surface than is true with the Moon.

c. From the above calculations, discuss your thoughts on the relative economics of mining water (to make rocket fuel) on the Moon versus carrying it from Earth.

Rocket launches from the Moon mean that you can carry more than twice the payload. Thus, mining water on the Moon is likely be much more cost-effective than carrying this from Earth.

7. (5 pts). Einstein's discovery that energy and mass are equivalent has led to technological developments that are both beneficial and dangerous. List as many of these developments as you can, categorizing them as positive, negative, or neutral. Overall, do you think the human race would be better or worse off if we had never discovered that mass is a form of energy. Defend your position.

Einstein's $E = mc^2$ equation has powerful implications. Among its consequences are:

- It explains how the Sun and every star in the universe works by using nuclear fusion, in which hydrogen and helium atoms fuse together while much of their mass is converted to energy. (positive)
- It explains the atomic energy produced by nuclear power plants which provides electricity around the world (positive) although these power plants also leave behind toxic radioactive waste (negative).
- The equation explains radioactivity. When radiology technicians use a radioactive substance to illuminate processes on the human body, $E=mc^2$ makes the technique possible. (positive)
- The equation is used in the radiocarbon technique which scientists use for dating objects. (positive)
- $E=mc^2$ is used in computer tomography (CT scans) and positron emission topography scans (PET scans). (positive)
- The equation accounts for the heat in the Earth's crust which is kept warm by a steady barrage of $E=mc^2$ conversions via radioactive decay. (positive)
- It explains what transpires at black holes. (positive)
- At the beginning of the universe, $E=mc^2$ is the only accepted explanation for what was going on in the first seconds after the Big Bang. Energy and matter went back and forth indiscriminately in exact accordance with the equation. (positive)

But, the conversion between mass and energy also allowed the development of nuclear bombs, the most potent weapon of mass destruction yet invented. Hundreds of thousands of Japanese civilians perished at the end of WWII as a result of the use of this weapon. Even more powerful weapons might be possible in the future as technology improves the conversion between matter and energy. (Big negative!)