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Last Name First Name

ASTR 2020, Fall 2020
Professor Jack Burns
Exam #1
September 21, 2020

INSTRUCTIONS: Closed books, one page (2 sides) of notes allowed, calculators may be used, ***strictly individual effort***. WRITE your name on this page BEFORE you begin the exam.

The exam consists of 10 multiple choice questions worth 4 points each, and 4 short answer questions worth 15 points each. *Please allocate your time accordingly among these parts of the exam.*

Multiple Choice. In questions 1-10, choose the best answer (2 pts). Then explain your reasoning in 1-2 complete sentences (2 pts). So, a correct answer and correct explanation is worth a total of 4 pts.

1. Which of the following is the **LEAST** persuasive reason for America's space program?
    a. To defend the United States against threats from other nations.
    b. To expand scientific frontiers and human knowledge.
    c. To improve our abilities to solve tough problems.
    d. To learn how to terra-form (i.e., transform) other planets to be like Earth.
    e. To create technological spin-offs and benefit the nation's economy.

Terraforming a planet (making its surface habitable) requires a giant leap in technologies and an enormous budget that puts it outside the realm of possibility for maybe a hundred years. The other issues are all ones that have been used to justify the space program since its earliest days. Defensive, Earth-remote sensing satellites are used to survey trouble-spots around the globe. Space observations and explorations have greatly expanding human knowledge. Space is tough and solving such problems improve our overall engineering and science capabilities. Technology spin-offs have been noted from the days of Apollo.

2. 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 (= g = 10 m/s^2) and t = time. So, after 5 seconds, the velocity is 10 m/s^2 $\times$ 5 s = 50 m/s.

3. If your mass is 60 kg on Earth, what would your mass be on the Moon?
    a. 10 lb
    b. 10 kg
    c. 50 kg
    d. 60 kg
    e. 60 lb

Mass is the same everywhere, independent of location and local gravity. So, a mass of 60 kg on Earth is also a mass of 60 kg on the Moon.

4. Why is Newton's version of Kepler's third law so useful to astronomers?
    a. It allows us to calculate distances to distant objects.
    b. It can be used to determine the masses of many distant objects.
    c. It tells us that more-distant planets orbit the Sun more slowly.
    d. It explains how mass and energy are related.
    e. It explains why objects spin faster when they shrink in size.

As derived during a class exercise, Newton's version of Kepler's 3rd Law states that

$$P^2 = \frac{4\pi^2}{GM} R^3$$

Where P is orbital period, R is the distance between the two masses in a system, and M is the total mass. So, by measuring P and R, you can calculate the mass.

5. The planets never travel in a straight line as they orbit the Sun. According to Newton's second law of motion, this must mean that
    a. the planets are slowly losing mass.
    b. the planets have a constant velocity.
    c. the planets have angular momentum.
    d. the planets will eventually fall into the Sun.
    e. a force is acting on the planets.

If a planet does not travel in a straight line, it means that its velocity or direction vector is changing. That means that the planet is experiencing centripetal acceleration. According Newton's second law, F = ma, if an object is accelerating, then a force is acting on it.

6. How does the SpaceX company's Falcon-9 rocket take off?
    a. Its rocket engines push against the launch pad propelling the spacecraft upwards.
    b. It converts mass-energy into 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 spacecraft moves in the opposite direction.
    e. The hot rocket exhaust expands the air beneath the spacecraft, propelling it forward.

a) is false; the rocket would propel itself even in the absence of a launch pad. b) is false because the Falcon uses chemical energy, not mass energy, through the use of rocket fuel. c) is false because the Falcon doesn't have wings. d) is True. e) is false; the rocket would propel itself even in the absence of air.

7. The goals for Project Mercury did **NOT** include which of the following
    a. To orbit a human-piloted spacecraft around Earth
    b. To land astronauts on the Moon and return them safely to Earth
    c. To investigate a human's ability to function in space
    d. To recover both astronaut and spacecraft safely

Apollo, not Mercury, landed astronauts on the Moon. Project Mercury's stated goals include a), c), and d).

8. The Rocket Equation
    a. can be derived beginning with Newton's Second Law of Motion.
    b. involves Conservation of Momentum during the firing of a rocket engine.
    c. can be used to show that a very large fraction of the mass of a rocket must be in fuel when taking off from the Earth's surface.
    d. applies to rockets on the surface of the Earth and in space.
    e. all of the above

a) The derivation starts with the general version of Newton's second law: $F = \frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t} = 0$.
b) In the above, setting F=0 (no external forces) means that there is no change in momentum.
c) The example in class of launch from Earth showed that the Mass Fraction of rocket fuel was over 88% of the total initial mass of the rocket.
d) The rocket equation works everywhere.

9. The fact that major portions of the Space Shuttle were reusable dramatically reduced the cost per pound of launching payloads into Earth orbit.
    a. True   b. False

Although this was the stated intention of the Space Shuttle, in reality, the expenses per launch grew to almost the same level as before the shuttle. So, this is false.

10. Suppose the Sun were suddenly to shrink in size but that its mass remained the same. According to the law of conservation of angular momentum, what would happen?
    a. The Sun would rotate faster than it does now.
    b. The Sun's rate of rotation would slow.
    c. The Sun's angular size in our sky would stay the same.
    d. This could never happen, because it is impossible for an object to shrink in size without an outside torque.

Conservation of Angular Momentum states: $L = m \times v \times r$, where L= angular momentum, m = mass, v = velocity, and r = radius. To keep L constant when the radius r is reduced, then v must increase. That means the Sun would rotate faster.

Short Answer Questions 11-14: Please answer the following questions in a few cogent sentences. Be sure to write legibly. Also, use sketches, if helpful, in addition to the text. Please be brief. Literacy and clarity count! **Each short answer is worth 15 points.**

11. The *New Horizons* spacecraft underwent a close flyby of the planet Jupiter on its way to Pluto. Why did NASA send it on such an indirect trajectory to Pluto? Justify your answer using a Conservation principle.

During the *New Horizons* fly-by of Jupiter, the spacecraft received a "gravitational assist" or "gravitational slingshot" to boost its velocity. This can be understood via conservation of energy and/or angular momentum in which Jupiter transfers a bit of orbital energy to *New Horizons* while the total energy remains constant. This allowed the spacecraft to reach Pluto a bit faster and with less fuel than would otherwise have been required with the gravitational assist.

12. State Newton's three Laws of Motion. Give an example of an application of each Law.

- **Newton's first law of motion:** An object moves at constant velocity unless a net force acts to change its speed or direction (inertia). When a rocket engine shuts down, the space vehicle will continue moving in a straight line at a constant speed.
- **Newton's 2nd Law:** Force = mass × acceleration, F = ma. More generally, Force = rate of change in momentum F = $\frac{\Delta p}{\Delta t}$. When an apple falls to the ground, it is accelerating. Newton concluded that a force (gravity) is acting on it.
- **Newton's 3rd Law:** For every force, there is always an *equal and opposite* reaction force. This is also a statement of the Conservation of Momentum. It is the reason that rockets move one direction (reaction) when the rocket engines fire exhaust in the opposite direction (action).

13. The first successful U.S. satellite placed in orbit of the Earth, Explorer 1, discovered the Van Allen belts.

   a. What are the Van Allen belts?

The Van Allen belts are zones of energetic particles which surround the Earth.

   b. What produces the Van Allen belts?

The Van Allen belts are produced by the interaction of solar wind particles from the Sun with the Earth's magnetic field. The particles get trapped and spiral around the field lines.

   c. Why was this discovery so important?

The discovery of the Van Allen belts was so important because the astronauts had to travel through them on their way to the Moon and knowing about them led to flight plans which minimized their time in the belts. The Van Allen belts also shield the ISS and other LEO satellites from high energy particles.

14. In the movie *Interstellar,* the spacecraft shown at right consists of a central core surrounded by a ring of habitat modules where the crew resides. The outer ring spins to create artificial gravity. If the radius of the ring is 10 meters, at what velocity must it spin to create the equivalent of 1g (10 m/sec^2) gravity? (Hint: think about centripetal acceleration.)

In order to simulate Earth's gravity, the rotation must generate an acceleration $1g$ in magnitude. Therefore, the centripetal acceleration $\frac{v^2}{r}$ must be equal to g. This means $g = \frac{v^2}{r}$, which is equivalent to $v = \sqrt{rg} = \sqrt{(10\ m)\left(10\ \frac{m}{s^2}\right)} = 10\ \frac{m}{s}$. So, the habitat ring with the astronauts must be rotating with a velocity of $10\ \frac{m}{s}$.