Introductory Astronomy

Homework 5: Newtonian Physics, Gravity, Orbits, Energy, Tides Not to be handed in. Homework solutions are posted already.

1. The contest in the 16th and 17th centuries in Europe between the geocentric and heliocentric world models was won by the heliocentric world model. The victory was a modified one. Heliocentricism no longer meant, as it did for Copernicus and Kepler, the Sun at the center of the universe, but only the Sun at the center of the planetary system of the Sun. The universe was generally taken to be much larger, perhaps infinite, and the stars recognized as perhaps other suns. The basis of the victory was that planetary and terrestrial motions were derived mathematically and with high accuracy from a small set of very abstract axioms (i.e., postulated physical laws) and initial conditions. The derived planetary motions conformed to the heliocentric view in that the Sun caused the planets to move as they did whereas the planets barely affected the motion of the Sun. From a geometrical point of view the Sun could be described as moving around the Earth or the Earth, around the Sun. This had long been recognized: e.g., probably by Ptolemy (circa 100–175 AD). The contested issue had not been geometrical description, but physical causation. The geocentric world model had been basically the Aristotelian one either in pure form (e.g., Aristotle's own system which was not even altogether qualitatively accurate) or in the Ptolemaic or Ptolemaic-like forms (which were or could be made quantitatively accurate). The Aristotelian world model had been based on Aristotelian physics. By modern standards Aristotelian physics is very unsatisfactory: it is almost entirely qualitative and is not always even qualitatively accurate and it is rather ad hoc (i.e., new principles need to be invented to explain new phenomena). One strength of Aristotelian physics was that in many instances it agreed with the common sense, concrete sense of the world: e.g., "the Earth's at rest or we'd feel it moving"; "a hammer falls faster than a feather." That Aristotelian physics and cosmology had been brought into concordance with Medieval theology was another strength in a time in which it was thought by many that the world should and did manifest the divine in an easily accessible manner. The theological concordance seemed to offer a guarantee of absolute truth, whereas the axiomatic, mathematical physics, only a provisional truth. The victory of the new physics and the new heliocentric system of the world showed that quantitative accuracy and mathematical elegance had come to be valued above naive common sense and naive concrete sense and that the religious objections could in fact be overcome. The victory was effectively completed by:
   a) Aristotle of Stagira (384–322 BC).
   b) Nicolaus Copernicus (1473–1543).
   c) Galileo Galilei (1564–1642).
   d) Johannes Kepler (1571–1630).
   e) Isaac Newton (1642/3–1727).

2. Drop a feather and hammer at the same time on the Earth and then on the Moon.
   a) They **both** hit the ground at the same time on both worlds.
   b) The **hammer** lands first by a large margin on both worlds.
   c) The **feather** lands first on both worlds.
   d) The **feather** lands second on Earth and at about the same time as the **hammer** on the Moon.
   e) The **feather** lands second on Earth and first by a large margin on the Moon.

3. What is the difference between speed and velocity?
   a) Velocity is the rate of change of speed.
   b) There is no difference.

c) The difference is merely theoretical, not practical.
d) Both measure the rate of change of position with time: velocity specifies direction as well as magnitude of the rate of change; speed specifies only magnitude.
e) Both measure the rate of change of position with time: velocity specifies acceleration as well as magnitude of the rate of change of position; speed specifies only magnitude of rate of change of position.

4. Newton's first law states:

a) a body continues at rest or in **ACCELERATED** motion in a straight line in an inertial frame unless acted on by a net force.
b) a body continues at rest or in **DECELERATED** motion in a straight line in an inertial frame unless acted on by a net force.
c) a body continues at rest or in **UNIFORM** (constant speed) motion in a straight line in an inertial frame unless acted on by a net force.
d) a body is **ALWAYS** at rest in an inertial frame unless acted on by a net force.
e) a body is always at rest in an inertial frame unless acted on by **GRAVITY**.

5. Newton's second law proposes that:

a) a body continues at rest or in **ACCELERATED** motion in a straight line in an inertial frame unless acted on by a net force.
b) for every force, there is an **equal** and **opposite** force.
c) a body continues at rest or in **UNIFORM** (constant speed) motion in a straight line in an inertial frame unless acted on by a net force.
d) a body is **ALWAYS** at rest in an inertial frame unless acted on by a net force.
e) an acceleration of a body is caused by a net force and the resistance of the body to acceleration is determined by a quantity called mass. In equation form the law is precisely

$$\vec{F}_{\rm net} = m\vec{a} \ ,$$

where $\vec{F}_{\rm net}$ is the net force, m is the body's mass, and $\vec{a}$ is the acceleration. Force and acceleration are both vectors (i.e., they have both magnitude and direction); mass is a scalar (i.e., it has only a magnitude).

6. Newton's third law states that for every force there is an equal and opposite force. But since two equal and opposite forces add vectorially to give zero, there should never be a net force and thus by Newton's second law there should never be any accelerations at all. What is the fallacy in this argument?

a) The fallacy is bringing Newton's second law into the argument. The second and third law refer to entirely different kinds of motions, and so can never be used at the same time.
b) There is none. The argument is completely valid. Accelerations are an illusion. So is motion for that matter. Parmenides of Elea (circa 5th century BC) was right: nothing changes; all change is but seeming.
c) The equal and opposite forces **DO NOT** have to be on the same body. Newton's second law refers to the net force on a single body. Thus, the net force on a body experiencing one of the pair of forces **NEED NOT** be zero. Thus accelerations **ARE** possible.
d) The equal and opposite forces **DO** have to be on the same body. Newton's second law refers to the net force on a single body. Thus, the net force on a body **NEEDS TO** be zero. Thus accelerations **ARE NOT** possible.
e) The full statement of the third law makes an **EXCEPTION** for forces that cause accelerations: there **DO NOT** have to be equal and opposite forces for acceleration-causing forces. Thus accelerations **ARE** possible.

7. Inertial frames are:
   a) rotating frames.
   b) accelerating frames.
   c) frames in which Newton's laws of motion **ARE** obeyed. They are all **UNACCELERATED** with respect to each other.
   d) frames in which Newton's laws of motion **ARE** obeyed. They are all **ACCELERATED** with respect to each other.
   e) frames in which Newton's laws of motion **ARE NOT** obeyed. They are all **UNACCELERATED** with respect to each other.

8. Newton's laws of motion are:
   a) obvious. This is why Aristotle knew them more than 23 centuries ago. He just rejected them for moral reasons.
   b) not obvious. Nevertheless, Aristotle knew of the them more than 23 centuries ago. He just rejected them for hygienic reasons.
   c) not obvious. To get to them, one probably first has to imagine what happens in the absence of all resistive media.
   d) 6 in number.
   e) not obvious. To get to them, one probably first has to imagine what happens in the center of the Earth.

9. A force is:
   a) what sustains a constant velocity.
   b) what sustains a uniform motion.
   c) the same as acceleration.
   d) a physical relation between bodies that causes them to accelerate (if not balanced by other forces).
   e) a physical relation between bodies that causes them to orbit each other.

10. Newton's force law for gravitation for the magnitude of the force is

$$F = \frac{GM_1M_2}{r^2} \; .$$

   a) The force is **ALWAYS ATTRACTIVE** and is felt only by the mass designated M_2. The distance between the centers of the two masses is $2r$. This force law strictly holds for **CUBICAL BODIES**.
   b) The force is **USUALLY ATTRACTIVE** and is felt by both masses M_1 and M_2. The distance between the centers of the two masses is r. Because r^2 appears in the denominator, the force law is an **INVERSE-CUBE LAW**. This force law strictly holds only for **POINT MASSES**: a **TOTALLY DIFFERENT FORCE LAW** applies to **SPHERICALLY SYMMETRIC BODIES**.
   c) The force is **ALWAYS ATTRACTIVE** and is felt by both masses M_1 and M_2. The distance between the centers of the two masses is r. Because r^2 appears in the denominator, the force law is an **INVERSE-SQUARE LAW**. This force law strictly holds only for **POINT MASSES**: a **TOTALLY DIFFERENT FORCE LAW** applies to **SPHERICALLY SYMMETRIC BODIES**.
   d) The force is **ALWAYS ATTRACTIVE** and is felt by both masses M_1 and M_2. The distance between the centers of the two masses is r. Because r^2 appears in the denominator, the force law is an **INVERSE-SQUARE LAW**. This force law applies to all **POINT MASSES** and also to **SPHERICALLY SYMMETRIC BODIES**. For nonspherically symmetric bodies, the force of gravitation **VANISHES**.

e) The force is **ALWAYS ATTRACTIVE** and is felt by both masses M_1 and M_2. The distance between the centers of the two masses is r. Because r^2 appears in the denominator, the force law is an **INVERSE-SQUARE LAW**. This force law applies to all **POINT MASSES** and also to **SPHERICALLY SYMMETRIC BODIES** outside of those bodies. For two **NONSPHERICALLY SYMMETRIC BODIES**, the force of gravitation can be calculated by finding the force between each pair of small parts (one of the pair from each of the two bodies) using the point-mass force law in its vector formulation. The forces between all the pairs can be added up vectorially to get the net force between the bodies.

11. Newton's force law for gravitation for the magnitude of the force is

$$F = \frac{GM_1M_2}{r^2} ,$$

where $G = 6.674 \times 10^{-11}$ is the gravitational constant in mks units, M_1 is the mass of one point mass, M_2 is the mass of a second point mass, and r is the distance between the two point masses. The law is usually presented as holding between point masses even though point masses are idealization that probably do not exist. Black holes may be true point masses, but they must be treated by general relativity or perhaps quantum gravity: they are outside of the realm of Newtonian physics and gravity.

Nevertheless, the law allows one to calculate the gravitational force between non-point masses by dividing them up into small bits each of which can be treated as a point mass. The net gravitational force on a single bit in the 1st body due to all the others in the 2nd body can then be found by vector addition of the individual bit gravitational forces. One then add up vectorially the gravitational forces on all the bits in the first body. This final sum is the net gravitational force of the 2nd body on the 1st body. The net gravitational force of the 1st body on the 2nd body is just equal and opposite by Newton's 3rd law. There is an approximation in that the bits are not point masses, but the smaller they are the more like point masses they become and the more accurate the result. The net gravitational force can thus be calculated as accurately as one likes and when calculated sufficiently accurately the net gravitational force always agrees with observations as long as one does not go to the strong gravity realm where general relativity is needed.

Fortunately, the gravity force law has several important special cases. It holds approximately between all bodies and becomes more accurate the further they are apart: it approaches being exact as the body separation becomes very large compared to the sizes of the bodies. Also a spherically symmetric body acts just like an ideal point mass with all the body mass concentrated at the center provided one is outside the body. Newton himself proved this result first: it was a vast relief to him and everyone else.

From the last paragraph of this disquistion, one can conclude that the gravity force law holds between a planet and small bodies on or above its surfaces:

a) only very crudely.
b) to high accuracy.
c) not at all.
d) only when the planet has a very high temperature.
e) only when the planet is green.

12. The force of gravity between two bodies is proportional to the inverse square of the distance between the centers of the two bodies either exactly or approximately depending on nature of the bodies. At 10 Earth radii, the Earth's gravity force is ________ times its gravity force on its surface.

a) 1/10 b) 1/20 c) 20 d) 1/100 e) zero

13. Newton's force law for gravitation for the magnitude of the force is

$$F = \frac{GM_1M_2}{r^2} ,$$

where $G = 6.674 \times 10^{-11}$ is the gravitational constant in mks units, M_1 is the mass of one point mass, M_2 is the mass of a second point mass, and r is the distance between the two point masses. The force is always attractive and always acts along the line joining the two point mass. The force can be viewed as either the force on 1 due to 2 or on 2 due to 1: this is consistent with the third law. Although strictly speaking the law has only been defined for point masses, the law can be applied approximately for non-point masses. Moreover, it is exactly correct for spherically symmetric masses, except inside of the masses. **CALCULATE** the force between two 1 kilogram point masses separated by a distance of one meter. **CALCULATE** the force between a kilogram mass at the surface of the Earth and the Earth ($M_\oplus = 5.9742 \times 10^{24}$ kg; $R_\oplus = 6.378136 \times 10^6$ m). The electromagnetic force holds small bodies like humans together: gravity clearly cannot do this. The electromagnetic force is obviously much stronger in some sense than the gravitational force. Why then does the gravitational force, not the electromagnetic force dominate the intermediate and large scale structure of the universe?

a) 6.674×10^{-11} newtons and 9.8 newtons. The electromagnetic force is generated by positive and negative charges. Positive and negative charges tend to cancel each other's effect when they are **CLOSE TOGETHER** and they are **HIGHLY ATTRACTIVE** to each other. On a microscopic scale, quantum mechanical effects keep the charges from exactly overlapping and cancelling each other. Thus very strong microscopic derived forces can exist: e.g., chemical and ionic bonding forces. These forces hold everyday materials together. But over large distances it is very **HARD** to develop a large net charge and thus the electromagnetic forces tend to cancel over large distances. Gravity has only one "charge," mass, and the gravitational force is always attractive. No cancelation is possible. Thus with large masses, the gravitational force can become large and have effects over large distances.
b) 6.674×10^{-11} newtons and 9.8 newtons. The electromagnetic force is generated by positive and negative charges. Positive and negative charges tend to cancel each other's effect when they are **CLOSE TOGETHER** and they are **HIGHLY REPULSIVE** to each other. On a microscopic scale, quantum mechanical effects keep the charges from exactly overlapping and cancelling each other. Thus very strong microscopic derived forces can exist: e.g., chemical and ionic bonding forces. These forces hold everyday materials together. But over large distances it is very **HARD** to develop a large net charge and thus the electromagnetic forces tend to cancel over large distances. Gravity has only one "charge," mass, and the gravitational force is always attractive. No cancelation is possible. Thus with large masses, the gravitational force can become large and have effects over large distances.
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other. Thus very strong microscopic derived forces can exist: e.g., chemical and ionic bonding forces. These forces hold everyday materials together. But over large distances it is very **EASY** to develop a large net charge and thus the electromagnetic forces tend to cancel over large distances. Gravity has only one "charge," mass, and the gravitational force is always attractive. No cancelation is possible. Thus with large masses, the gravitational force can become large and have effects over large distances.

e) 6.674×10^{-11} newtons and 9.8 newtons.

14. The acceleration due to gravity near the surface of the Earth is:

$$a = \frac{GM_\oplus}{R_\oplus^2} = 9.8\,\mathrm{m/s^2}$$

to 2-digit accuracy. Say you are a skydiver and—in a momentary lapse—have forgotten your parachute (golden or otherwise). Imagine there is no air resistance. What will be your speed after 10 s? In kilometers per hour? (The conversion factor is 3.6 (km/hr)/(m/s).) In reality, what mitigates your predicament?

a) About 100 m/s or 360 km/hr. Air resistance opposes the your downward motion and in fact increases with your downward velocity. Thus, eventually, you stop accelerating and reach a terminal velocity. For skydivers this is $\sim$ 200 km/hr. You won't accelerate to the ground. So in reality your **SURVIVAL** is guaranteed.
b) About 10 m/s or 36 km/hr. Air resistance opposes the your downward motion and in fact increases with your downward velocity. Thus, eventually, you stop accelerating and reach a terminal velocity. For skydivers this is $\sim$ 200 km/hr. You won't accelerate to the ground. So in reality your **SURVIVAL** is guaranteed.
c) About 100 m/s or 360 km/hr. Air resistance opposes the your downward motion and in fact increases with your downward velocity. Thus, eventually, you stop accelerating and reach a terminal velocity. For skydivers this is $\sim$ 200 km/hr. You won't accelerate to the ground. Nevertheless, the landing will be **VERY HARD**. But some people have survived such falls.
d) About 10 m/s or 36 km/hr. Air resistance opposes the your downward motion and in fact increases with your downward velocity. Thus, eventually, you stop accelerating and reach a terminal velocity. For skydivers this is $\sim$ 200 km/hr. You won't accelerate to the ground. Nevertheless, the landing will be **VERY HARD**. But some people have survived such falls.
e) About 9.8 m/s or 36 km/hr. Air resistance opposes the your downward motion and in fact increases with your downward velocity. Thus, eventually, you stop accelerating and reach a terminal velocity. For skydivers this is $\sim$ 200 km/hr. You won't accelerate to the ground. Nevertheless, the landing will be **VERY HARD**. But some people have survived such falls.

15. In uniform circular motion the acceleration always:

a) is formally infinite. Of course, there is really no acceleration, but the mathematical calculation always comes out infinite.
b) is zero.
c) points **in the direction of motion** and has magnitude v^2/r, where v is the speed and r is the circle radius. The acceleration is called the **tangential acceleration**.
d) points **toward** the center and has magnitude v^2/r, where v is the speed and r is the circle radius. The acceleration is called the **centripetal acceleration**.
e) points **away from** the center and has magnitude v^2/r, where v is the speed and r is the circle radius. The acceleration is called the **centrifugal acceleration**.

16. The velocity of a smallish body in a circular orbit about a large spherically symmetric mass is given by

$$v = \sqrt{\frac{GM}{r}} ,$$

where M is the mass of the central object and r is the radius of the orbit. This expression is derived using:

a) Newton's 1st law, the force law of gravity, and the kinematic result for centripetal acceleration (i.e., the magnitude of the acceleration is v^2/r).
b) Newton's 2nd law, the force law of gravity, and the kinematic result for centripetal acceleration (i.e., the magnitude of the acceleration is v^2/r).
c) Newton's 3rd law, the force law of gravity, and the kinematic result for centripetal acceleration (i.e., the magnitude of the acceleration is v^2/r).
d) Newton's 3rd law, Coulomb's law, and the kinematic result for centripetal acceleration (i.e., the magnitude of the acceleration is v^2/r).
e) from nothing at all. It is a fundamental law. It is a "just so" of nature.

17. The escape velocity for a small body from a large spherically symmetric body is

$$v = \sqrt{\frac{2GM}{r}} ,$$

where M is the mass of the large body, r is the radius from which the launch occurs (which could be on or anywhere above the body), and $G = 6.674 \times 10^{-11}$ is the gravitational constant in mks units. The launch can be any direction at all as long as only gravity acts on the small body: you cannot let the small body hit the planet.

Calculate the escape velocity from the Earth given $M = 5.9737 \times 10^{24}\,\text{kg}$ and $r = 6.378136 \times 10^{6}\,\text{m}$ (which is the Earth's equatorial radius). Give the answer in km/s.

a) 7.91 km/s. b) 0.791 km/s. c) 1.0×10^{-3} km/s. d) 11200 km/s. e) 11.2 km/s.

18. Space debris is:

a) space heating, b) the same thing as ultraviolet radiation, c) space junk, d) the remains of a Romulan attack, e) has the last "s" pronounced.

19. Up until Saturday 1998 October 24, all interplanetary probes had been accelerated when in flight by chemical-burning rocket propulsion. (Note: On said Saturday of 1998 October, NASA launched Deep Space 1, an ion propulsion probe: the non-linear effects of science fiction keep turning up.) These kind of probes (i.e., chemical-burning rocket propulsion probes) periodically get accelerated by brief rocket firings.

a) The paths of these probes cannot be described by orbits at all: before, during or after firings.
b) Between firings the probes travel along **particular orbits**. The firings change the orbits. A **sufficiently strong firing** would cause a probe to reach **escape speed** for the solar system. After such a firing the probe goes into an **open orbit**.
c) Between firings the probes travel along **particular orbits**. The firings change the orbits. An **extremely weak firing** causes a probe to reach **escape speed** for the solar system. After such a firing the probe **falls into the Sun**.
d) Between firings the probes travel along **particular orbits**. The firings change the orbits. A **sufficiently strong firing** would cause a probe to reach **escape speed** for the solar system. After such a firing the probe **falls into the Sun**.

e) Between firings the probes travel along **particular orbits**. The firings change the orbits. A **sufficiently strong firing** would cause a probe to reach **escape speed** for the solar system. After such a firing the probe goes into an **elliptical orbit**.

20. "Let's play *Jeopardy*! For $100, the answer is: It is sometimes described as the capability of causing change or transformation albeit this is not at all a full definition."

    What is ____________, Alex?

    a) a force   b) a horse   c) energy   d) gravity   e) electromagnetism

21. Kinetic energy is the energy of:

    a) motion.   b) the electromagnetic field.   c) electromagnetic radiation.   d) rest mass.
    e) speediness.

22. Energy:

    a) comes in many forms which are all interconvertible **without any restrictions**.
    b) comes in many forms which are all interconvertible. However, **whether or not** a conversion occurs or not depends initial conditions and on a complex set of rules: these rules come from force laws, conservation laws, and quantum mechanics, but **NOT** thermodynamics.
    c) comes in many forms which are all interconvertible. However, **whether or not** a conversion occurs or not depends initial conditions and on a complex set of rules: these rules come from force laws, conservation laws, quantum mechanics, **AND** thermodynamics.
    d) comes in the form of kinetic and heat energy only.
    e) comes in the form of rest mass energy only.

23. The Einstein equation is:

    a) $E = c^2$,   b) $E = mc^2$,   c) $E = mc^3$,   d) $E = m$,   e) $E = m/c^2$.

24. An everyday example of the 2nd law of thermodynamics is that:

    a) heat flows from **hot to cold bodies** (at least at the macroscopic level) provided there is no refrigeration process or absolute thermal isolation in effect.
    b) heat cannot flow at all.
    c) heat flows from **cold to hot bodies** (at least at the macroscopic level) provided there is no refrigeration process or absolute thermal isolation in effect.
    d) heat and coolness are both fluids.
    e) heat is a fluid and coolness is relative absence of that fluid.

25. Entropy is:

    a) the same as temperature.
    b) the same as heat.
    c) a measure of magnetic field energy.
    d) a **physically** well-defined kind of disorder.
    e) a **spiritually** well-defined kind of disorder.

26. The world's largest tidal range is:

    a) of order 0.5 m in the deep oceans.   b) 1 m in the Bay of Fundy.   c) 12 m or more in the Bay of Fundy.   d) 0.1 m or less in the Bay of Fundy.   e) 12 m or more in Lake Erie.

27. Compared to ocean coastal tides, small lake coastal tides are usually:

    a) unnoticeably small. b) large. c) about the same. d) slightly smaller, but quite noticeable. e) much larger.

28. The tides (the terrestrial tides that is) are

    a) the periodic rise and fall of the waters of the **LAKES AND STREAMS** with a primary period of about **12 HOURS, 25 MINUTES**. The tides are caused by the tidal currents which in turn are caused by the tidal forces of **PRIMARILY THE MOON** and **SECONDARILY THE SUN**.
    b) the periodic rise and fall of the waters of the **OCEANS AND THEIR INLETS** and all waters bodies to some degree (sometimes minute) with a primary period of about **2 HOURS, 25 MINUTES**. The tides are caused by the tidal currents which in turn are caused by the tidal forces of **PRIMARILY THE SUN** and **SECONDARILY THE MOON**.
    c) the periodic rise and fall of the waters of the **OCEANS AND THEIR INLETS** and all waters bodies to some degree (sometimes minute) with a primary period of about **12 HOURS, 25 MINUTES**. The tides are caused by the tidal currents which in turn are caused by the tidal forces of **PRIMARILY THE MOON** and **SECONDARILY THE SUN**.
    d) the periodic rise and fall of the waters of the **OCEANS AND THEIR INLETS** and all waters bodies to some degree (sometimes minute) with a primary period of about **2 HOURS, 25 MINUTES**. The tides are caused by the tidal currents which in turn are caused by the tidal forces of **PRIMARILY THE MOON** and **SECONDARILY THE SUN**.
    e) the periodic rise and fall of the waters of the **OCEANS AND THEIR INLETS** and all waters bodies to some degree (sometimes minute) with a primary period of about **29.531 DAYS**. The tides are caused by the tidal currents which in turn are caused by the tidal forces of **PRIMARILY THE SUN** and **SECONDARILY THE MOON**.

29. Currently, the Moon's tidal effect on the Earth (principally through the frictional force of the tides on the Earth's seabeds) is increasing the Earth's solar day by about 0.0014 seconds per century averaged over many centuries. The standard 24 hour day we use with precisely defined seconds (set by atomic clocks) was in fact close to being exactly a solar day **circa year 1820**. Currently, (i.e., circa year 2000) the solar day is about 86400.002 s. In order to keep the atomic-clock-generated time we actually use synchronized with solar time, leap seconds have to be added periodically to the atomic-clock-generated time. About how often would this be at the present time? **HINTS:** You could try checking out some course links, although the calculation is trivial actually. You could also just ask yourself a simpler question—if my watch runs a second fast per day, how many days will it be before it is one minute ahead of standard time?—and see if that helps.

    a) About every 500 days. b) About every 365 days. c) About every 50,000 years. d) About every month. e) About every day.

30. The mean Earth-Moon distance is 3.844×10^{10} cm. Currently tidal interaction is increasing this distance by 3 cm/yr as we know from bouncing laser beams off reflectors on the Moon left by the Apollo missions. Assuming that the rate of increase is constant (which is actually unlikely), how long until the mean Earth-Moon distance is twice its current value?

    a) 3.844×10^{10} s. b) 3.844×10^{10} yr. c) 1.281×10^{10} s. d) 1.281×10^{10} yr. e) 400 yr.

31. Synchronously tidally locked to an orbital companion usually means:

    a) that a body has an average rotation period that to a high accuracy **EQUALS** its average revolution period about that orbital companion and that this situation was brought about by the **COMPANION'S** tidal force.

b) that a body has an average rotation period that to a high accuracy **EQUALS TWICE** its average revolution period about that orbital companion and that this situation was brought about by the **COMPANION'S** tidal force.
c) that a body has an average rotation period that to a high accuracy **EQUALS TWICE** its average revolution period about that orbital companion and that this situation was brought about by the **BODY'S OWN** tidal force.
d) that a body has an average rotation period that to a high accuracy **EQUALS** its average revolution period about that orbital companion and that this situation was brought about by the **BODY'S OWN** tidal force.
e) that no tidal force is present.