Introductory Astronomy

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

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005 qmult 00100 1 5 5 easy thinking: victory of Newtonian heliocentrism

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).

   SUGGESTED ANSWER: (e) An easy thinking question after the long harangue.

   Wrong answers:
   a) Aristotle was the patron of the old physics and system.
   b) He started the contest, he didn't end it.
   c) Galileo obviously didn't triumph and he wasn't the completer of the victory—he was a great intermediate figure.
   d) Kepler wasn't able to convince most of the world of heliocentric system and didn't invent much anyway of the new physics.
   e) Newton was born 1642dec25 on the Julian calendar used in England all of this life. This 1643jan04 on the modern Gregorian calendar that was used in most of the rest of Europe at

that time.

Redaction: Jeffery, 2001jan01

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005 qmult 00200 1 1 4 easy memory: hammer and feather on Moon

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.

   SUGGESTED ANSWER: (d)

   Wrong answers:
   a) The air resistance on Earth slows down the feather.
   b) On the Moon, the air resistance is negligible.

   Redaction: Jeffery, 2001jan01

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005 qmult 00300 1 1 4 easy memory: speed and velocity

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.

   SUGGESTED ANSWER: (d) Velocity is vector. Vectors specify both a magnitude and a direction.

   Wrong answers:
   e) A nonsense answer.

   Redaction: Jeffery, 2001jan01

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005 qmult 00400 1 1 3 easy memory: Newton's 1st law

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**.

   SUGGESTED ANSWER: (c) The right answer is also the longest answer.

Wrong answers:

b) Deceleration is usually defined as an acceleration that points opposite to the direction of velocity.

Redaction: Jeffery, 2001jan01

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005 qmult 00410 1 4 5 easy deducto memory: Newton's 2nd law

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).

SUGGESTED ANSWER: (e) The right answer is also the longest answer.

Wrong answers:

b) This is the 3rd law.
c) This is the 1st law.

Redaction: Jeffery, 2001jan01

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005 qmult 00510 1 5 3 easy thinking: Newton's 3rd law and accelerations

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.

SUGGESTED ANSWER: (c)

Wrong answers:

b) It is probably wrong to believe that Parmenides really did not believe that motion occurred. Rather he was presenting a philosophic argument based on premises that led to that conclusion. Philosophy, among other things, is the search for true premises and valid means of deriving conclusions from them.

d) This answer (which isn't an answer to the question) just makes the fallacy explicit by saying the equal and opposite forces do have to be on the same body.

e) Did you ever, ever here me mention such an exception. Actually there are forces that are exceptions to the third law, but I didn't talk about them. But the exceptions are not the reason why the argument is fallacious.

Redaction: Jeffery, 2001jan01

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005 qmult 00550 1 5 3 easy thinking: inertial frames

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.

SUGGESTED ANSWER: (c)

Wrong answers:

d) From somewhere I recall Newton did once think about having 6 laws of motion, but decided to settle on 3.

Redaction: Jeffery, 2001jan01

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005 qmult 00580 2 5 3 moderate thinking: Newton's laws not obvious

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.

SUGGESTED ANSWER: (c) This is really a thinking question, if the Professor has not spoken ex cathedra.

Wrong answers:

a) If Newton's laws were obvious, why did they take so long to be discovered and why don't students just know them.
b) Aristotle: not likely.
d) There are only 3.

e) The center of the Earth is a red herring.

Redaction: Jeffery, 2001jan01

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005 qmult 00600 1 1 4 easy memory: force definition

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.

SUGGESTED ANSWER: (d)

Wrong answers:

e) This only happens in some cases. But it's not a general statement of what a force is.

Redaction: Jeffery, 2001jan01

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005 qmult 00900 2 5 5 moderate thinking: gravitation law

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.

SUGGESTED ANSWER: (e) It can be just a straight memory question, but some thought can narrow the answers down. The students have to grasp the additivity of gravitation. This is seldom explicitly discussed in elementary classes, but it is sort of implied.

In general relativity a repulsive gravitational force can arise in theory and there is evidence that such a repulsive gravity force is accelerating the expansion of the universe. But the Newtonian gravity force is always attractive: i.e., within Newton's theory of gravity, gravity is always attractive.

Wrong answers:

a) This violates Newton's 3rd law of motion.
b) The gravitational force is always attractive and inverse cube law is wrong from the formula itself, but some students may be weak on cubes. But they could recall that the law does apply to spherical bodies.
c) They could recall that the law does apply to spherical bodies.
d) Gravity is obviously doesn't vanish for nonspherical bodies: even that apple was not perfectly spherical.

Redaction: Jeffery, 2001jan01

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005 qmult 00910 2 5 2 moderate thinking: gravity force law approximations

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

$$F = \frac{GM_1 M_2}{r^2} ,$$

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.

SUGGESTED ANSWER: (b) Since a spherically symmetric body acts just like a point mass and a point mass has no size and the separation between a planet center and small objects on or above its surface is large compared to a point mass or to the small objects, one must conclude that the gravity force law must hold to high accuracy.

Wrong answers:
e) Green? Why the devil should green have anything to do with it?

Redaction: Jeffery, 2001jan01

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005 qmult 01000 1 5 4 easy thinking: inverse-square law of gravity

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

SUGGESTED ANSWER: (d) People do have to understand what an inverse square law means.

Wrong answers:
a) This would be the result of just an inverse law.

Redaction: Jeffery, 2001jan01

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005 qmult 01100 1 5 1 easy thinking: gravity dominates large scales

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.

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

d) 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 **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.

SUGGESTED ANSWER: (a) Long, but the checking through the logic of each answer has pedagogic value.

Wrong answers:

b) They are attractive. If they were repulsive, then perhaps the world would be either full of clumps of positive and negative matter or perhaps would be all gases depending on which alternative laws of physics one prescribes.

Redaction: Jeffery, 2001jan01

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005 qmult 01110 1 5 3 easy thinking: free fall, terminal velocity

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.

SUGGESTED ANSWER: (c)

Wrong answers:
a) 200 km/hr is devastating enough.
b) Same as (a), but with the wrong speed too.
d) wrong speed.
e) This is to make answers (e) and (d) look beguilingly attractive, to any you don't understand acceleration really.

Redaction: Jeffery, 2001jan01

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005 qmult 01200 1 4 4 easy deducto-memory: centripetal acceleration
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**.

SUGGESTED ANSWER: (d)

Wrong answers:
a) Oh, c'mon.

Redaction: Jeffery, 2001jan01

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005 qmult 01210 1 4 2 easy deducto-memory: circular orbital velocity

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.

SUGGESTED ANSWER: (b)

Wrong answers:
d) Coulomb's law is the electrostatic force law.
e) Oh, c'mon.

Redaction: Jeffery, 2001jan01

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005 qmult 01220 1 3 5 easy math: escape velocity from Earth

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 $M = 5.9737 \times 10^{24}$ kg and $r = 6.378136 \times 10^{6}$ 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.

SUGGESTED ANSWER: (e) See Cox-240 for the Earth's equatorial radius.

Fortran Code

```
        gg=6.674e-11
        xmass=5.9737e+24
        rr=6.378136e+6
        vv1=sqrt(gg*xmass/rr)
        vv=sqrt(2.*gg*xmass/rr)
        print*,'vv1,vv'
        print*,vv1,vv
*            7905.61    11180.2
```

Wrong answers:

a) This is the circular orbital velocity at the Earth's surface. You obtain this by omitting the $\sqrt{2}$ factor in the formula.
d) You forgot to convert to km/s.

Redaction: Jeffery, 2001jan01

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005 qmult 01280 1 4 3 easy deducto-memory: space debris

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.

SUGGESTED ANSWER: (c)

Wrong answers:

d) At age 9, I deduced that this was the definition.
e) No one ever says debrissss.

Redaction: Jeffery, 2001jan01

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005 qmult 01350 3 5 2 easy thinking: changing orbits

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**.

SUGGESTED ANSWER: (b) A tough educational question. The student has to think about orbits, open and closed (i.e., elliptical) and what escape speed means. It would help if they understood that between firings only the force of gravity acts on the probe causing it to move in some particular definite orbit.

Wrong answers:

a) Between firings (which are very short) the probes are traveling in gravitationally determined orbits.
c) A weak firing wouldn't cause a probe to achieve escape speed. And why then fall into the Sun?
d) Why fall into the Sun if the probe can escape.
e) With an escape speed, a probe would be in an open orbit: it's out of here: viz. the solar system.

Redaction: Jeffery, 2001jan01

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005 qmult 01380 1 4 3 easy deducto-memory: energy definition

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

SUGGESTED ANSWER: (c) See the faint-hearted assaults on energy by KB-66, HRW-117, and Fr-367. None of them attempts a full definition and French says that a general definition may not be possible. But I've tried.

Wrong answers:

a) Well forces can cause change, but they arn't usually described as in the preamble.
b) Well, I sure horses sometimes cause change.

Redaction: Jeffery, 2001jan01

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005 qmult 01400 1 1 1 easy memory: kinetic energy

21. Kinetic energy is the energy of:

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

SUGGESTED ANSWER: (a)

Wrong answers:

e) I don't see how this noun could be considered the best answer.

Redaction: Jeffery, 2001jan01

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005 qmult 01410 1 1 3 easy memory: energy conversions

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.

SUGGESTED ANSWER: (c)

Wrong answers:

b) Thermodynamics through the 2nd law puts definite constraints on how energy can be converted.

Redaction: Jeffery, 2001jan01

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005 qmult 01402 1 1 2 easy memory: Einstein equation identified

23. The Einstein equation is:

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

SUGGESTED ANSWER: (b)

Wrong answers:
e) As Lurch would say: “Aaaarh.”

Redaction: Jeffery, 2001jan01

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005 qmult 01450 1 5 1 easy thinking: 2nd law of thermodynamics

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.

SUGGESTED ANSWER: (a)

Wrong answers:
b) Everyone knows heat flows.
c) Hot coffee gets cold; cold coffee never gets hot.
d) Heat and coolness are not fluids.
e) Coolness may be a relative absence of heat, but heat is not a fluid.

Redaction: Jeffery, 2001jan01

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005 qmult 01460 1 4 4 easy deducto-memory: entropy
Extra keywords: physci

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.

SUGGESTED ANSWER: (d)

Wrong answers:
a) Why would we have an obscure synonym for temperature? Yeah, I know we could, but we don’t.
b) Why would we have an obscure synonym for heat? Yeah, I know we could, but we don’t.
c) No.
e) This takes out of the realm of science, to a realm in which entropy can only have a rather metaphoric meaning.

Redaction: Jeffery, 2001jan01

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005 qmult 01500 1 4 3 easy deducto-memory: Fundy Tides

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.

SUGGESTED ANSWER: (c) Wells, p. 247, says 14 meters; Defant, p. 14, says almost 70 feet or 20 odd meters: there may be no inconsisency; Defant may be just pointing to an extreme case even for Fundy. But I don't recall who Wells or Defant are. But Seeds (Se-37) says 12 meters or more, and I'll rely on that.

Wrong answers:
a) This is about the size of deep ocean tides, but they arn't the world's largest. No one I can find gives a consistent answer on the real range of deep ocean tides.
b) Right place, wrong range.
d) Right place, wrong range.
e) Lake Erie. Come on. Port Colborne would be washed away.

Redaction: Jeffery, 2001jan01

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005 qmult 01510 1 4 1 easy deducto-memory: lake tides
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.

SUGGESTED ANSWER: (a) A super everyday observation question. Does Lake Erie have an obvious tide; does Lake Meade? Does one see a tide in a glass of water. But actual physical understanding is tough. See Defant p. 65, but that doesn't help enough.

Wrong answers:
b) C'mon.

Redaction: Jeffery, 2001jan01

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005 qmult 01600 1 4 3 easy deducto-memory: tides discussed
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**.

SUGGESTED ANSWER: (c)

Wrong answers:
a) Lakes and streams have some tidal flow, but it is really minute and so this can't be the answer to a definition question.
b) Tides don't have such a short period: they come in and go out every couple of hours. Also the Moon is the primary cause of tides.
d) The Moon, not the Sun, is primary tidal driver.
e) 29.531 days is the lunar month which certainly is one of the periodicities of the tides, but not the primary one.

Redaction: Jeffery, 2001jan01

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005 qmult 01800 2 5 1 moderate thinking: leap seconds

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.

SUGGESTED ANSWER: (a) The solar days are now about 0.002 seconds longer than the standard day. Therefore the standard day clock gains 0.002 seconds per day on the solar day clock. To accumulate 1 second of gain will take

$$\frac{1\,\mathrm{s}}{0.002\mathrm{s/day}} = 500\,\mathrm{days}\ .$$

Check out `http://tycho.usno.navy.mil/leapsec.html` . Leap seconds tend to be added on January 1 or July 1 as needed.

Wrong answers:
b) This would make life too easy.

Redaction: Jeffery, 2001jan01

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005 qmult 02000 1 3 4 easy math: increasing Earth-Moon distance

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.

SUGGESTED ANSWER: (d) Well the calculation is simple:

$$\frac{3.844 \times 10^{10}}{3} = 1.281 \times 10^{10}\ \mathrm{yr}\ .$$

Wrong answers:

c) Wrong units.

Redaction: Jeffery, 2001jan01

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005 qmult 02100 1 4 1 easy deducto-memory: synchronous tidal locking

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.

SUGGESTED ANSWER: (a)

Wrong answers:

b) This is the case for Mercury, but that is unusual tidal locking.
c) Not twice and the companion's tidal force causes the locking.
d) The companion's tidal force causes the locking.
e) Even when the body is tidally locked, the tidal force is present causing the stretching of the body along the body-companion line against its own gravity.

Redaction: Jeffery, 2001jan01