Introductory Astronomy **NAME:**

Homework 5: Physics, Gravity, Orbits, Thermodynamics: Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems ($\sim$ 50–70 %) will turn up on tests.

Answer Table

Name:

	a	b	c	d	e		a	b	c	d	e
1.	O	O	O	O	O	37.	O	O	O	O	O
2.	O	O	O	O	O	38.	O	O	O	O	O
3.	O	O	O	O	O	39.	O	O	O	O	O
4.	O	O	O	O	O	40.	O	O	O	O	O
5.	O	O	O	O	O	41.	O	O	O	O	O
6.	O	O	O	O	O	42.	O	O	O	O	O
7.	O	O	O	O	O	43.	O	O	O	O	O
8.	O	O	O	O	O	44.	O	O	O	O	O
9.	O	O	O	O	O	45.	O	O	O	O	O
10.	O	O	O	O	O	46.	O	O	O	O	O
11.	O	O	O	O	O	47.	O	O	O	O	O
12.	O	O	O	O	O	48.	O	O	O	O	O
13.	O	O	O	O	O	49.	O	O	O	O	O
14.	O	O	O	O	O	50.	O	O	O	O	O
15.	O	O	O	O	O	51.	O	O	O	O	O
16.	O	O	O	O	O	52.	O	O	O	O	O
17.	O	O	O	O	O	53.	O	O	O	O	O
18.	O	O	O	O	O	54.	O	O	O	O	O
19.	O	O	O	O	O	55.	O	O	O	O	O
20.	O	O	O	O	O	56.	O	O	O	O	O
21.	O	O	O	O	O	57.	O	O	O	O	O
22.	O	O	O	O	O	58.	O	O	O	O	O
23.	O	O	O	O	O	59.	O	O	O	O	O
24.	O	O	O	O	O	60.	O	O	O	O	O
25.	O	O	O	O	O	61.	O	O	O	O	O
26.	O	O	O	O	O	62.	O	O	O	O	O
27.	O	O	O	O	O	63.	O	O	O	O	O
28.	O	O	O	O	O	64.	O	O	O	O	O
29.	O	O	O	O	O	65.	O	O	O	O	O
30.	O	O	O	O	O	66.	O	O	O	O	O
31.	O	O	O	O	O	67.	O	O	O	O	O
32.	O	O	O	O	O	68.	O	O	O	O	O
33.	O	O	O	O	O	69.	O	O	O	O	O
34.	O	O	O	O	O	70.	O	O	O	O	O
35.	O	O	O	O	O	71.	O	O	O	O	O
36.	O	O	O	O	O	72.	O	O	O	O	O

1. Did you complete reading the Introductory Astronomy Lecture before the **SECOND DAY** on which the lecture was lectured on in class?

   a) YYYessss! b) Jawohl! c) Da! d) Sí, sí. e) OMG no!

2. "Let's play *Jeopardy*! For $100, the answer is: This person was the first to understand the planetary motions using a physical theory that very adequately accounted for terrestrial motions."

   a) Ptolemy (circa 100–175 CE). b) Nicolaus Copernicus (1473–1543).
   c) Isaac Newton (1642/3–1727). d) Richard Feynman (1918–1988).
   e) Stephen Hawking (1942–2018).

3. Drop a feather and hammer at the same time on the Earth (given realistic conditions) and then on the Moon (also given realistic conditions).

   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.

4. 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.

5. The dynamic variable ________ is the resistance of a body to acceleration. The fact that gravitational force depends on ________ was one of those curious coincidences that led Einstein to formulate general relativity.

   a) acceleration b) force c) angular momentum d) mass e) emass

6. Inertial frames are:

   a) rotating frames.
   b) accelerating frames.
   c) frames with respect to which all physical laws are referenced (at least in the usual sense), except general relativity which tells us that exact inertial frames are free-fall frames. To be concrete, the center of mass of a system of astro-bodies (which may consist of just one astro-body) that only interacts with the rest of the universe through gravity defines an exact inertial frame (i.e., a free-fall frame) and this frame **DOES NOT** rotate with respect to the observable universe. Any part of the system **NOT** accelerating with respect to the center of mass also defines an exact inertial frame relative the center-of-mass inertial frame. Parts of system accelerating sufficiently slowly relative to the center-of-mass inertial frame are approximate inertial frames for some effects. To give an example, the Earth center of mass defines an inertial frame. Any location on the surface of the Earth is accelerated with respect to the Earth center-of-mass inertial frame because of the Earth's rotation, and so **IS NOT** an exact inertial frame relative to the Earth center-of-mass inertial frame, but is an approximate inertial frame for many effects.
   d) frames with respect to which all physical laws are referenced (at least in the usual sense), except general relativity which tells us that exact inertial frames are free-fall frames. To be concrete, the center of mass of a system of astro-bodies (which may consist of just one astro-body) that only interacts with the rest of the universe through gravity defines an exact inertial frame (i.e., a free-fall frame) and this frame DOES rotate with respect to the observable universe.
   e) frames with respect to which all physical laws are referenced (at least in the usual sense), except general relativity which tells us that exact inertial frames are free-fall frames. To be concrete, the center of mass of a system of astro-bodies (which may consist of just one astro-body) that only interacts with the rest of the universe through gravity defines an exact inertial frame (i.e., a free-fall

frame) and this frame does **NOT** rotate with respect to the observable universe. Any part of the system **NOT** accelerating with respect to the center of mass also defines an exact inertial frame relative the center-of-mass inertial frame. Parts of system accelerating sufficiently slowly relative to the center-of-mass inertial frame are approximate inertial frames for some effects. To give an example, the Earth center of mass defines an inertial frame. Any location on the surface of the Earth is accelerated with respect to the Earth center-of-mass inertial frame because of the Earth's rotation, and so **IS** an exact inertial frame relative to the Earth center-of-mass inertial frame.

7. 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 or between a body and a the field of some force that causes a body to accelerate (if not balanced by other forces).
   e) a physical relation between bodies that causes them to orbit each other.

8. 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.

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

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

where $G = 6.67430 \times 10^{-11}$ 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 disquisition, 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.

10. 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

11. In the early 1590s when he was a professor (untenured) at the University of Pisa, Galileo probably performed a public demonstration of dropping balls from the Leaning Tower of Pisa. The idea was to show that Aristotle was wrong in saying that balls of different masses fell in markedly different times. But the balls never fell in quite the same time. This was because:

    a) of the gravitational perturbation of Jupiter.
    b) according to Newton's laws the acceleration of a ball under gravity is proportional to its mass.
    c) according to Newton's laws the acceleration of a ball under gravity is inversely proportional to its mass.
    d) they had differing air resistance and probably Galileo's inability to release them at exactly the same time.
    e) they had the same air resistance and the fact that Galileo was standing tilted because of the tower's tilt.

12. 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 ~ 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 ~ 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 ~ 200 km/hr. You won't accelerate to the ground. Nevertheless, the landing will be **VERY HARD**. But some people have survived such falls.

13. 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 $G = 6.67430 \times 10^{-11}$ 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 $M = 5.9722 \times 10^{24}$ kg and $r = 6.3781370 \times 10^6$ 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.

14. Astronauts in orbit about the Earth are weightless because:

a) gravity vanishes in space.
b) gravity becomes repellent in space.
c) they are in free fall. They are perpetually falling away from the Earth.
d) they are in free fall. They are perpetually falling toward the Earth, but keep missing it.
e) they are in free fall. But they reach terminal speed due to air resistance and this hides any effects of acceleration.

15. 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**.

16. "Let's play *Jeopardy*! For \$100, the answer is: Everyone admits that there is no adequate one-sentence definition of fundamental quantity X of physics and the natural world in general. Nevertheless, it is useful to have even an inadequate one-sentence definition as a starting point for further specification. Yours truly, at this moment in time, suggests the following: X is the conserved capability of change. Conserved means X cannot be created or destroyed though it can be transformed among different forms and transferred through space. The "capability of change" means, among other things, the amount of

X added to or subtracted from a system dictates, without other specified information, the amount of change in an unspecified sense that must occur in that system—except that the change in X itself is specified. X and its spectrum of forms are characteristics of the state of a system, but they are far from being the only ones—but they are the most general characteristics since all states have X and at least some forms of X, but not necessarily all other characteristics. X and its spectrum of forms are always calculated by formulae from more direct observables: e.g., velocity, position, electric field. Outside of the realm of physics, a vague semi-quantitative version of X under various names has probably been used throughout much of human existence to mean capability of change, transformation, or doing something in many different realms.

What is ____________, Alex?

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

17. Kinetic energy is the energy of:

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

18. The formula for kinetic energy is

$$KE = \frac{1}{2}mv^2 \ ,$$

where m is mass and v is velocity. If velocity is doubled, kinetic energy changes by a multiplicative factor of:

a) 2. b) 4. c) 1/2. d) 1/4. e) 1 (i.e., it is unchanged).

19. 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.

20. The Einstein equation is:

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

21. The Einstein equation

$$E = mc^2 \ ,$$

where E is an amount of energy, m is mass, and c is the vacuum speed of light, can be read correctly in two ways. First, it can be read as saying all forms of energy have mass (i.e., resistance to acceleration and gravitational "charge") equal to E/c^2, where E is the amount of the energy. Second, it can be read as saying:

a) the vacuum speed of light is a form of energy.
b) the square of the vacuum speed of light is a form of energy.
c) the equal sign is a form of energy.
d) that rest mass (the resistance to acceleration of matter in a frame in which it is at rest) is a form of energy with the amount of energy being equal to the rest mass times c^2. We usually refer to rest mass simply as "mass" without qualification when there is no danger of confusion. Because rest mass is a form of energy it can be converted into any other form. Usually in terrestrial conditions one **CAN** completely convert the rest mass of a macroscopic body to another form of energy easily.
e) that rest mass (the resistance to acceleration of matter in a frame in which it is at rest) is a form of energy with the amount of energy being equal to the rest mass times c^2. We usually refer to rest mass simply as "mass" without qualification when there is no danger of confusion. Because rest mass is a form of energy it can be converted into any other form, but usually in terrestrial

conditions one **CANNOT** completely convert the rest mass of a macroscopic body to another form of energy easily.

22. 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.

23. 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.

24. One way of stating the 2nd law of thermodynamics is that:

    a) entropy (a physically well-defined kind of **DISORDER**) always increases or stays the same for a closed system. For an open system, it can decrease. When entropy is constant in a closed system, then that system is in **THERMODYNAMIC EQUILIBRIUM**.
    b) entropy (a physically well-defined measure of **TEMPERATURE**) always increases or stays the same for a closed system. For an open system, it can decrease. When entropy is constant in a closed system, then that system is in **THERMODYNAMIC EQUILIBRIUM**.
    c) entropy (a physically well-defined kind of **DISORDER**) always increases or stays the same for a closed system. For an open system, it can decrease. When entropy is constant in a closed system, then that system is **NOT IN THERMODYNAMIC EQUILIBRIUM**.
    d) entropy (a physically well-defined measure of **TEMPERATURE**) always increases or stays the same for a closed system. For an open system, it can decrease. When entropy is constant in a closed system, then that system is **NOT IN THERMODYNAMIC EQUILIBRIUM**.
    e) heat flows from **COLD TO HOT BODIES SPONTANEOUSLY** (at least at the macroscopic level) when they are in thermal contact (i.e., they are not thermally insulated from each other).