1. (B) Work = \( fd \cos 60^\circ = (10 \text{ N})(2.5)(0.5) = 12.5 \text{ J} \)

2. (C) 
   
   \[ 
   \text{Power} = \frac{\text{work}}{\text{time}} = \frac{(fd \cos 120^\circ)/T}{(mg \cos 120^\circ)(D/T)} 
   \]
   
   \[ = \frac{(3)(10)(-0.5)(10 \text{ m/s})}{-150 \text{ W}} \]

3. (C) 
   
   \[ W = \Delta KE \]
   
   \[ \mu ND \cos 180^\circ = 0 - \frac{1}{2} mv^2 \]

   \[ (\mu mgD)(-1) = -\frac{1}{2} mv^2 \]

   \[ D = \frac{v^2}{2\mu g} = 100/(2 \times 0.2 \times 10) = 25 \text{ m} \]

4. (D) Conservation of energy: 
   
   \[ KE = EPE = \frac{1}{2} kx^2 \]

   Since we need \( x \) to double, increase \( x \) by \( (2)^{\frac{1}{2}} = \sqrt{2} \).
5. **(D)** The 30° and 60° angles will have equal ranges but with the roles of $V_x$ and $V_y$ reversed. Therefore, the projectile launched at a 30° angle will not go as high. Note that mass does not enter into projectile motion problems.

6. **(B)** 45° gives the maximum range for a projectile as it is splitting the initial velocity evenly between vertical (giving you time in flight) and horizontal (giving you speed downrange). Angles above or below will have shorter ranges. Approaching the 45° angle will increase the range:

$$\text{Range} = \left(\frac{v_0^2}{R}\right) \sin 2q$$

7. **(C)**

$$\frac{1}{2} kx^2 = mgh$$

$h = \frac{kx^2}{2mg}$ above the starting point. Since the release point is a distance $x$ above the starting point, we must subtract $x$ from the answer.

8. **(D)** $F = kx$. So when graphing $f$ versus $x$, $k$ will be the slope. The extension of the spring is $x$ when $F$ is the force applied to the spring.

9. **(A)**

$$F\Delta t = \Delta p$$

$$(F)(15 \text{ s}) = 0 - (2,500)(30) = -75,000 \text{ kg} \cdot \text{m/s}$$

$$F = -5,000 \text{ N}$$

The negative sign indicates an opposing force. Note that weight is not needed in this calculation, so the value of $g$ is irrelevant.

10. **(C)** Momentum is always conserved. However, kinetic energy is lost unless the collision is elastic, in which case the kinetic energy is also conserved:

$$p_i = 1(+6) + 2(+3) = 12 \text{ kg m/s} = p_f = 3v_f$$

$$v_f = 4 \text{ m/s}$$

Initial KE:

$$\left(\frac{1}{2}\right)(1)(6)^2 + \left(\frac{1}{2}\right)(2)(3)^2 = 27 \text{ J}$$

Final KE:

$$\left(\frac{1}{2}\right)(3)(4)^2 = 24 \text{ J}$$

3 joules are lost.
11. (D) Impulse = \( \Delta p = p_f - p_i = 0.2(-l) - (0.2)(3) = -0.8 \text{ kg} \cdot \text{m/s} \)

12. (B) 
\[
\frac{1}{2} kA^2 = \text{total energy when } x = A \text{ (all PE, no KE)}
\]
\[
\frac{1}{2} mv_{\text{max}}^2 = \text{total energy when } x = 0 \text{ (all KE, no PE)}
\]
Conservation of energy:
\[
\frac{1}{2} kA^2 = \frac{1}{2} mv_{\text{max}}^2
\]
\[
v_{\text{max}} = (k/m)^{\frac{1}{2}} A
\]

13. (B) In one cycle, the mass travels 4 amplitudes:
\[
A = 0.02 \text{ m}
\]
Energy = \[
\frac{1}{2} kA^2 = \frac{1}{2} (50)(0.02)^2 = 0.01 \text{ J}
\]

14. (D) Orbital velocity:
\[
F_c = \text{centripetal force} = \frac{mv^2}{R}
\]
\[
GMm/R^2 = \frac{mv^2}{R}
\]
\[
v = (GM/R)^{\frac{1}{2}}
\]
Escape velocity:
\[
E_{\text{total}} > 0
\]
\[
\text{KE + PE} > 0
\]
\[
\frac{1}{2} mv^2 - GMm/R > 0 \text{ (using universal gravitational PE)}
\]
\[
v > (2GM/R)^{\frac{1}{2}}
\]

15. (B) The gravitational force between two masses has a \( 1/R^2 \) relationship (where \( R \) is the distance from center to center). Graph B shows the correct inverse relationship.

16. (C) Since node to node is half a wavelength:
\[
\lambda = 0.4 \text{ m}
\]
\[
f = v/\lambda = 5/0.4 = 12.5 \text{ Hz}
\]
17. **(C)** Resistivity is only part of the resistance of a wire:

\[ R = \frac{\rho L}{A} \]

Therefore, a less conductive material (lower \( \rho \)) can be made equal in resistance to a more conductive material by making the less conductive material shorter and/or fatter (lower \( L \) or larger \( A \)).

18. **(C)** At maximum height, all speed is from \( V_x \):

\[ V_x = 200 \cos 30° = 173 \text{ m/s} \]

19. **(A)** Vertical forces must cancel:

\[ T \cos \theta - mg = 0 \]
\[ T = \frac{mg}{\cos \theta} \]

20. **(D)** \( v = \frac{p}{m} = \frac{(2 \times 1 + 3)}{2} = 2.5 \text{ m/s} \)

21. **(B)** Since \( F \Delta t = \Delta p \), a net force will change the linear momentum. However, torque also involves the lever arm \( (\tau = RF\sin \theta) \). So despite having a nonzero net force, the net torque might still be zero.

22. **(C)** Circular motion:

\[ F_{\text{net}} = \frac{mv^2}{R} \]
\[ mg - N = \frac{mv^2}{R} \]

\( N \) is the force the car exerts on the driver:

\[ mg - \frac{mv^2}{R} = (500 - 50)(20^2)/50 = 500 - 400 = 100 \text{ N} \]

Note that the correct answer can be found by simply knowing that the net force must be down and that the car must be pushing upward on the passenger.

23. **(C)** Take the center of mass to be 1 meter from the pivot:

Net torque = \(+mg(1)\sin 90° - 200(2)\sin 30°\)
\[ = 98 - 200 = -102 \text{ N} \cdot \text{m} \]

24. **(D)** Resonance is the sympathetic vibration of an object when impacted by a wave with the same frequency as its own fundamental frequency of oscillation.
25. **(D)**

Resistors in series = 2\(R\)
Resistors in parallel = \(R/2\)
Difference = 1.5\(R\)
Ratio = \(2R/(R/2) = 4\)

26. **(C)** Batteries store energy, which is measured in joules:

\[
\text{Energy} = \text{power} \times \text{time} = I \times V \times \text{time} = (40 \text{ A})(12 \text{ V})(3,600 \text{ s})
\]

\[
= 1,728,000 \text{ J}
\]

27. **(C)** Coulomb’s law is \(kQ_1Q_2/R^2\). Tripling \(Q_1\) triples the force. Tripling \(R\) makes the force 9 times weaker. Net effect:

\[
3 \times 1/9 = 1/3
\]

28. **(C)**

Torque = \(I\alpha\)
\[\alpha = \text{angular acceleration} = \Delta\omega / \Delta t\]

Our only data provided are that the angular acceleration must be larger for the 75 RPM record and that the moment of inertia has not changed (same disk). Therefore, the torque supplied must be larger.

29. **(A)** Remember conservation of energy. Since both start at the same height (same PE) with the same kinetic energy, they will both hit the ground with same joules of energy (all KE). The same KE means the same speed since their masses are the same. Note that this does not imply that both components of velocity are the same. They are not. This implies that only the magnitudes of the final velocity vectors are the same.

30. **(C)** The vertically projected sphere will spend much more time in the air as it goes much higher. Without knowing the exact speed of the launch, it is not possible to say by what factor the time in flight is extended.

31. **(A)** The change in gravitational potential energy is the same for both. Therefore the work done by gravity is the same.

32. **(C)** Friction is the only force that is directed inward toward the center of the circle. By definition, all centripetal forces must be directed inward. To confirm this, imagine the path the car would take on a frictionless stretch of track.
33. (D) \( \frac{mv^2}{r} = \frac{(2,000 \times 50^2)}{250} = 20,000 \, \text{N} \)

34. (B) Remember Newton’s third law. The forces are equal and opposite.

35. (A) Universal gravity is a \( 1/R^2 \) law. Doubling \( R \) makes the force 4 times weaker.

36. (B) No horizontal acceleration means no change in horizontal velocity.

37. (C) Charge is quantized (comes in integer multiples only) in units of \( \pm 1.6 \times 10^{-19} \, \text{C} \).

38. (B) Sound is a longitudinal wave.

39. (C) The Doppler shift of waves that occurs when the source and receiver are moving toward each other causes a shorter wavelength and hence a higher frequency.

40. (D) The elevator must be traveling at constant velocity to insure the normal force (reading on the scale) is the same as her true weight. However, this velocity value can be any number: positive, zero, or negative.

41. (C) Remember that \( g = Gm/R^2 \). Half the mass means half the \( g \). Half the \( R \) means 4 \times \( g \). Collect the changes:

\[
\frac{1}{2} \times 4 = 2
\]

42. (D) Forces cause mass to accelerate linearly. Torques cause moments of inertia to accelerate angularly.

43. (A) Inertia is the tendency of an object to continue its motion in the absence of other forces. As the train stops, the passengers continue forward until a force is brought to bear directly on them.

44. (C) Constant velocity means no acceleration. No acceleration means no net force. The friction opposing weight must be equal in magnitude to that weight.

45. (A) Constant acceleration means precisely that. For the same time interval, the change in velocity will be the same.
46. (A) and (D) Constant angular velocity means zero angular acceleration, which means no net torque.

47. (B) and (D) Since the vertical velocity is zero, only height is needed to determine the drop time:

\[ H = \frac{1}{2} gt^2 \]

Knowing the final vertical velocity would also allow one to determine the time since:

\[ V_{yf} = 0 - gt \]

48. (B) and (D) The skater’s center of mass must remain above her skates. Since no external torques are involved in drawing her arms inward, her momentum is conserved. Note that her moment of inertia decreases and her angular velocity increases.

49. (A) and (B) If the 3 forces are in the same direction, \( F_{net} = 15 \text{ N} \), which is the maximum possible force. In this situation, the acceleration is 1 \( \text{m/s}^2 \). If the 3 forces are 120° apart from each other in direction, they would add up to zero and produce no acceleration.

50. (A) and (C) Both \( R_1 \) and \( R_2 \) are connected in parallel to the same two points that the voltmeter is measuring the potential difference between. Therefore, the voltmeter reading is that same voltage drop for both \( R_1 \) and \( R_2 \). Note that an ideal ammeter has no resistance and thus experiences no voltage drop itself.

**Section II: Free-Response**

1. (a) For various measured compressions of the spring \( x \), measure horizontal range for the mass \( R \). Range should be measured along the floor from beneath the edge of the table to where the mass first hits the ground. Multiple trials for each compression \( x \) should be taken so that the average range of values can be determined.

(b) The independent variable is the one the experimenter controls and manipulates directly. In this case, the independent variable is the compression \( x \). The dependent variable is the one measured as a result of changes in the independent variable. In this case, the dependent variable is the range. Independent variables are graphed on the horizontal axis. Theoretical prediction:

\[
\frac{1}{2} kx^2 = \frac{1}{2} mv^2 \\
\nu = (k/m)^{1/2} x
\]
This velocity is the horizontal projectile’s velocity. The time in flight is found from the height of the table:

\[ H = \frac{1}{2} gt^2 \]

1.6 m = 4.9\(t^2\)

\[ t = 0.57 \text{ s} \]

\[ R = vt = \left(\frac{k}{m}\right)^{1.5}xt = .57(\frac{k}{m})^{1.5}x \]

Using the fixed values for \(m\) and \(t\):

\[ R = 0.806k^{1.5}x \]

(c) The major source of error is friction of the tabletop between the end of the spring and the edge of the table. Ensuring that this distance is small and that the surfaces involved are smooth will minimize this error.

(d)

The discontinuity is probably caused by exceeding the limit of elasticity for this spring. Hooke’s law assumes that the material is perfectly elastic and resumes its shape after being stretched or compressed:

\[ \text{Slope} = 20 = 0.806k^{1.5} \text{ (from part (b))} \]

Solving for \(k\):

\[ k = 616 \text{ N/m} \]
2. (a) 

a. Upward acceleration, feel heavy

\[ \text{Diagram of upward acceleration with forces:} \]

\[ N \quad \text{Normal force} \]
\[ mg \quad \text{Weight} \]

b. No acceleration, feel normal

\[ \text{Diagram of no acceleration with forces:} \]

\[ N \quad \text{Normal force} \]
\[ mg \quad \text{Weight} \]

c. Downward acceleration, feel light

\[ \text{Diagram of downward acceleration with forces:} \]

\[ N \quad \text{Normal force} \]
\[ mg \quad \text{Weight} \]

d. Downward acceleration, feel light

\[ \text{Diagram of downward acceleration with forces:} \]

\[ N \quad \text{Normal force} \]
\[ mg \quad \text{Weight} \]

e. No acceleration, feel normal

\[ \text{Diagram of no acceleration with forces:} \]

\[ N \quad \text{Normal force} \]
\[ mg \quad \text{Weight} \]

f. Upward acceleration, feel heavy

\[ \text{Diagram of upward acceleration with forces:} \]

\[ N \quad \text{Normal force} \]
\[ mg \quad \text{Weight} \]
(b) A person’s mass is a measure of his or her inertia. This value does not change due to acceleration or changes in location. Gravitational weight is a force due to the interaction of the person’s mass and the planet on which he or she is standing (including the distance between their centers). Although technically this value is slightly smaller as you get higher above sea level, the differences within a building on Earth are negligible. Apparent weight is the contact forces your body experiences, which give you your subjective experience of “weight.” In this case, the normal force and the changing values of the normal force explain the changes the person would experience on the elevator ride.

(c) The elevator and passenger would experience free fall. The only force would be the downward \( mg \), and the normal force would be zero. Hence, the person would feel weightless. Since the car was on the way up when the cables broke, both passenger and elevator would maintain the same relative velocity to each other as both continued upward, slowed down, and then reversed direction and continued to speed up while falling. The entire time, the passenger would feel weightless.

(d)

3. (a) The spinning probe acts as a gyroscope since angular momentum is both a vector and conserved. The direction of the angular momentum requires an external torque to be changed. Therefore, barring some outside force, the probe will maintain the orientation it has when the angular velocity is given to its moment of inertia:

\[ L = I \omega \]
(b) By extending the masses outward from the probe’s body, the moment of inertia of the spinning probe can be greatly increased. Note that the masses need not be that great in order to change the moment of inertia substantially as the distance, \( R \), from the axis of rotation can be made quite large by using a long cable and the \( R \) term is squared in the moment of inertia calculation:

\[ I = mR^2 \]

Increasing the moment of inertia serves to slow the spin rate of the probe by decreasing the angular velocity in order to conserve angular momentum:

\[ L_{\text{small}}\omega_{\text{large}} = L_{\text{large}}\omega_{\text{small}} \]

(c) Linear momentum (\( mv \)) of the probe-planet system must be conserved. Equal and opposite impulses (\( F\Delta t \)) are delivered to the probe and the planet during impact. However, because of their vastly different masses, what is a major impulse to the probe turns out to be a moderate impulse to the entire planet and has almost no perceptible effect on the planet’s motion:

\[ M_{\text{probe}}\Delta V_{\text{big}} = M_{\text{big}}\Delta V_{\text{small}} = 0 \]

4. (a) When the cars meet, the position of each car, relative to a common origin, must be the same. Since each car is starting from rest and accelerating uniformly:

\[ d_1 = d_2 \]
\[ \frac{1}{2} xt^2 + 25 = \frac{1}{2} yt^2 \]

\[ y - x = 50/t^2 \]

Clearly, the second car must have a larger acceleration \((y > x)\). The difference between the two accelerations must increase as time to catch up \((t)\) gets smaller. So there is no upper limit on how much faster car \( y \) must accelerate than car \( x \) to catch up within 10 seconds. There is, however, a lower limit on the difference. This can be found by examining the case when the second car takes the full 10 seconds:

\[ y - x = 50/t^2 = 50/100 = 0.5 \]

Thus we see that for the second car to catch up with the lead car within the first 10 seconds, the second car must accelerate at least 0.5 m/s\(^2\) faster than the first car.
(b) No, they will never have either the same instantaneous speed or the same average speed. The second car is always faster:

![Graph](image)

The second car has a slope of $y$ on this graph, while the first car has a slope of $x$. Since $y > x$, one can see that neither the instantaneous nor the average slopes of either of these plots is ever the same.

(c) The second car will be ahead as it will have the higher speed when the two meet. Therefore, for the rest of the trip, the second car will cover more ground and come out ahead. To find out by how much, we can compare their speed when they meet:

$$v_1 = xt \quad v_2 = yt$$

where $t$ is the exact time (within the first 10 seconds) when they meet.

$$\Delta d = v_2(10) - v_1(10) = 10(yt - xt) = (y - x)10t$$

Substitute our algebraic expression from part (a):

$$\Delta d = \frac{500}{t}$$

Once again, there is no upper bound on the difference in distance. However, there is a lower bound that can be found by setting $t$ equal to 10 seconds:

$$\Delta d > 50 \text{ m}$$

(d) __X__ The second car expended more energy.

No matter the details, more work was done in moving the second car as it had the greater acceleration. Greater acceleration (with the same mass) means greater force. Since the displacements are the same, the greater force means more work:

$$W = Fd$$
5. (a) First, technically your fellow student is correct. As the top of the cliff is 200 meters farther from the center of Earth, the gravitational field experienced by the rock at the top of the cliff is technically weaker:

\[ g_{\text{top}} = \frac{GM_{\text{Earth}}}{(R + 200)^2} \quad \text{versus} \quad g_{\text{bottom}} = \frac{GM_{\text{Earth}}}{R^2} \]

Since the radius of Earth is \(6.38 \times 10^6\) m, adding a mere 200 m does not make much of a difference:

\[
\frac{200}{(6.38 \times 10^6)} = 3 \times 10^{-5}
\]

Therefore for all practical purposes, the difference in gravitational field strength is so minimal that treating \(g\) as a constant acceleration is fairly reasonable.

On the moon, one would expect a greater deviance since 200 meters is a greater fraction of the Moon’s radius (\(1.7 \times 10^6\)). However, any decrease in the moon’s gravitational effects would also be negligible;

\[
\frac{200}{(1.7 \times 10^6)} = 1 \times 10^{-4}
\]

(b) Somewhere along a line between \(M\) and \(9M\) but closer to \(M\) should be a position such that the force of attraction for \(M\) will cancel the force of attraction for \(9M\). Let the distance between the third mass \((m)\) and \(M\) be \(x\):

\[
\frac{GmM}{x^2} = \frac{Gm(9M)}{(d - x)^2}
\]

Cancel and simplify:

\[
9x^2 = (d - x)^2
\]

Take the square root of both sides:

\[
\pm 3x = d - x
\]

This leads us to two solutions:

\[
x = \frac{d}{4}
\]

which is the expected solution between the masses and

\[
x = -\frac{d}{2}
\]

which is an unexpected solution on the outside of mass \(M\) along the same line. Note that in both solutions, the new mass \(m\) is 3 times farther away from \(9M\) than it is from \(M\).
TEST ANALYSIS

NOTE: Because the AP Physics 1 and AP Physics 2 are new exams (first administered in 2015), there is no way of knowing exactly how the raw scores on the exams will translate into a 1, 2, 3, 4, or 5. The formula provided below is based on past practice for the AP Physics B and commonly accepted standards for grading. Additionally, the score range corresponding to each grade varies from exam to exam and thus the ranges provided below are approximate.

AP PHYSICS 1 PRACTICE TEST 2

Section I: Multiple-Choice

Note that the questions requiring two answers are to be graded as completely correct or incorrect.

Number correct (out of 50) = \text{Multiple-Choice Score}

Section II: Free-Response

Grade each question individually using the following scale:

- 4: completely correct
- 3: substantially correct with minor errors
- 2: partially correct with some incorrect parts
- 1: a few correct attempts made, but no completely correct portions
- 0: completely incorrect or unanswered

\begin{align*}
\text{Question 1} &= \frac{\text{score}}{4} \\
\text{Question 2} &= \frac{\text{score}}{4} \\
\text{Question 3} &= \frac{\text{score}}{4} \\
\text{Question 4} &= \frac{\text{score}}{4} \\
\text{Question 5} &= \frac{\text{score}}{4} \\
\text{Total} &= \frac{\text{score}}{20} \times 2.5 = \text{Free-Response Score}
\end{align*}

Final Score

\begin{align*}
\text{Multiple-Choice Score} \times \text{Free-Response Score} \approx \text{Final Score} \quad \text{(rounded to the nearest whole number)}
\end{align*}

<table>
<thead>
<tr>
<th>Final Score Range</th>
<th>AP Score</th>
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<td>81-100</td>
<td>5</td>
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<tr>
<td>61-80</td>
<td>4</td>
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<td>3</td>
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