ACES – Academic Challenge

Physics Solutions (Regional) – 2024

1. **Correct Response: B**

The force of gravity is often mg and the height is a distance so mgh is the same units.

1. **Correct Response: A**

First we get the components of B

Now we get the components of C. Note that 40° from the +y axis is actually 130° from the +x axis.

We are now ready to find the components of T

So T is given by

1. **Correct Response: C**

In kinematics for a system with constant acceleration we get

We are given that the time is 6.00 minutes (or 360 seconds), the distance is 177km or 177000m, and the initial velocity is 0.00. So

Solving for a gives us 2.731 m/s2.

1. **Correct Response: A**

In kinematics for a system in freefall we know that the acceleration is g and we can set the coordinate system such that up is positive and down is negative so we would have the vertical equation of motion as follows:

We are told that the height above the ground is 36.6 m and that the initial velocity is purely horizontal so the y component of the velocity is zero. So this equation becomes:

Solving for t gives us 2.732 s.

1. **Correct Response: D**

We can do a force diagram at the point of the intersection of the three strings. From that we will see that the tension in the third string is just enough to hold the mass up. That is,

The tension in the other two strings must have a vertical component that would counteract the tension in the third string. So

The horizontal components of these two tensions must also sum to zero.

We now have three equations and three unknowns. From the third we can solve for T1 and from the first we can solve for T3 and we can plug both into the second equation to get:

Solving that equation for T2 gives us 43.21 N.

1. **Correct Response: C**

Given that the position equation is given by:

To find the velocity we only have to take the derivative with respect to time.

To find the time at which the velocity is zero we set this equation to zero.

From that we determine that the time when the velocity is zero is 1.4606 s. Next we find the second derivative:

This gives us the acceleration at the time that we found above: 21.91 m/s2.

1. **Correct Response: E**

Carbon 14 with the symbol has 6 protons and 14 nucleons. The 14 also represents its approximate atomic weight in grams per mole. We should also understand that in each atom 6 of the nucleons are protons meaning that 8 of the nucleons are neutrons. So we must multiply the total number of moles of atoms by 8 for the number of neutrons.

1. **Correct Response: A**

The force applied to the mass follows Newton’s Law.

We also see that it will take the same time to come to a complete stop as it will to accelerate back up to speed vo. So let’s determine the distance to stopped. The change in velocity is governed by the kinematic equation for velocity:

which can be solved for time.

The kinematic equation for position is

The negative sign is because the acceleration is in the opposite direction to the initial velocity. We can plug the above time into this equation to get the distance the object travels before it comes to rest:

Setting the origin to be the starting point we can see that this leads to

This is the distance until it stops. It then reverses the motion so it doubles the distance traveled.

1. **Correct Response: E**

We are given the speed and the time so we easily find the distance:

1. **Correct Response: E**

The power is given by so to be negative in terms of the dot product we need the angle between F and v to be such that the cosine of it is negative. Of course, the time would be positive so for the work to be negative the dot product must be negative. The cosine is negative between 90° and 180°. That is the only choice that includes those angles.

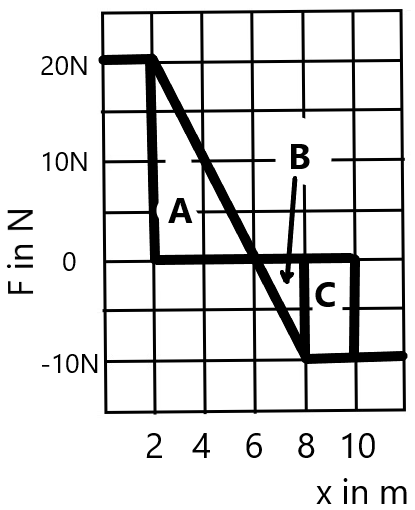
1. **Correct Response: E**

This is the conservation of angular momentum

The information has the rotation listed as 0.830 rev/s. Angular velocity in the answers is written in rad/s. So we need to convert to those.

1. **Correct Response: B**

The work done is the area under the curve. We can do this piecewise. We break it up as shown below into A, B, and C:



Then using the area of a triangle as ½ bh and realizing that B and C are negative due to being below the x axis:

1. **Correct Response: B**

The forces acting on the block on the incline are gravity, the normal force, and the tension in the string. Gravity has a component normal to the surface and parallel to the surface. The force parallel to the surface is given by:

the total force on M2 in the direction parallel to the surface is zero so we get:

The forces acting on M1 are the tension in the string, gravity, the normal force, and the force of friction. In the vertical direction we have:

In the horizontal direction we have:

the force of friction depends on the coefficient of static friction and the normal force:

Putting these equations together we get:

We can solve this for the coefficient of friction

1. **Correct Response: A**

The system is now able to move so the equation for the mass on the incline becomes:

where we are considering the direction down the slope to be positive. The horizontal equation for the mass on the horizontal surface becomes:

Solving these equations for a by solving for T in the first and plugging it into the second we get:

1. **Correct Response: D**

This is a static equilibrium problem. We can determine the torques on the shelf using the axis of rotation at the point of the pin connection with the wall. The forces to consider now are the center of mass of the shelf, the force from the cat, Malcolm, and the support bar which is applied at an angle of 45°. The torque equation is

Solving for F gives us; F = 126.623 N.

1. **Correct Response: C**

Potential Energy of a Spring:

1. **Correct Response: D**

The energy given the mass by the spring will be equal to the work done on the mass from friction once the mass comes to rest.

Solving for d gives:

1. **Correct Response: C**

The acceleration of the car is simply given by

The wheels rotate without slipping so we consider a wheel rolling without slipping with a linear acceleration and also note that r is half of the diameter.

We now have to convert radians to revolutions: 302.052/2 = 48.073 rev

1. **Correct Response: C**

The power output of the muscle car changes the kinetic energy of the vehicle. The rate of change of the kinetic energy is the power output.

Next we convert this power output to horsepower:

1. **Correct Response: B**

The total spring constant for this system has a spring constant that is the sum of the two springs. So:

We need to convert this to a frequency in Hz.

1. **Correct Response: E**

The internal energy for monatomic molecules in thermodynamics is given by

So only depends on the number of molecules and the temperature. For this problem we have held the number of molecules constant so the temperature is the only variable that the internal energy depends on.

1. **Correct Response: C**

The conservation of energy applies here. We have a pendulum that is 2.76 m long. The maximum height reached happens when the angle of the pendulum is 28.9°. At that time the speed is zero so there is no kinetic energy. If we consider the angle of zero degrees as being the vertical origin then the height is measured from that point. Then the height at maximum angle is:

Similarly we can calculate the height when the angle is 6.43° as:

The conservation of energy states that the potential plus the kinetic energy of the system stays constant:

As we stated, the initial velocity is zero and the goal is to find the final velocity. The masses divide out so that

We solve this for vf

1. **Correct Response: C**

The tension in the string is what the scale measures and this tension is the same all along the string because of the pulley. A force diagram would show two tension arrows pointed upwards along both sections of string leaving the pulley. The force downward is mg and this force is balanced by the two tensions that are evenly distributed. Thus the tension must be .

1. **Correct Response: B**

We start this problem by determining the decibels of the sound at Katie’s first location.

Turning that volume down by 4.20 dB brings it to 69.302 dB. That means that the new intensity at that point is found through solving for I2 in:

This gives us I1f = 8.5162x10-6 W/m2. Now we need to determine what that intensity would be at the new location. The sound spreads out as r2 so we can set it up as a ratio:

We know everything here except I2 so we can solve:

1. **Correct Response: D**

The position of the spaceship relative to the center of the Earth is RT = RE + r. The force of gravity depends on the distance between the centers of the objects here. So to move in a circular orbit the centripetal acceleration must be from the force of gravity. That is:

This can be solved for the speed, v, to get:

1. **Correct Response: C**

The impulse imparted to the ball is the integral under the curve in the graph. In this case it is the area under the triangle.

The impulse is also the change in momentum of the baseball:

So that

1. **Correct Response: E**

As the alcohol is added, the upwards buoyant force increases and the wood rises until it is completely out of the glycerin. Because the densities of the wood and the alcohol are equal, when the wood is completely submerged in alcohol, the upwards buoyant force (which by Archimedes’ principle is equal to the weight of the displaced fluid) and the downward weight force of the wood exactly balance, and the wood block will rest in equilibrium just above (at) the glycerin surface.

1. **Correct Response: D**

The activity of the Neptunium is given by the equation:

Where Ao is the initial activity and  is the decay constant. The decay constant is related to the halflife by:

So we have to determine the halflife from the equation:

Solving for T1/2 gives 2.3491 days.

1. **Correct Response: E**

This is a dimensional analysis problem. We simply plug in the dimensions as shown.

1. **Correct Response: C**

The conservation of momentum breaks down into an x and a y equation. For the x equation we would have

This reduces to

And in the y direction we get:

So that we have

So that, by the Pythagorean Theorem:

1. **Correct Response: B**

Magnification is given by where m is the magnification, S is the object distance, and S’ is the image distance. We plug this into the lens equation to obtain:

This can be rearranged to give us:

When the image is focused on the screen the total length between the object and the screen is the sum of the object distance and the image distance.

Putting these two together we have

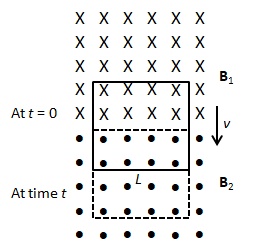
We can now solve this for f (we know L= 9.16 m and m = -86.9

1. **Correct Response: D**

In relativistic addition of velocities if they are moving toward each other we have:

1. **Correct Response: D**

As can be seen in the diagram below, at *t* = 0, the total magnetic flux through the coil is zero. When the coil moves downward, more magnetic field lines are piercing the area of the coil and pointing out of the page.



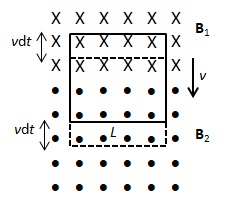
According to Lenz’s Law, the induced current opposes such change by producing magnetic field lines pointing into the page within the loop. By the right-hand-rule, the induced current is in the clockwise direction.

1. **Correct Response: C**

According to Faraday’s Law of Induction, |*ε*| = *N*(d*Φ*/d*t*), where |*ε*| is the magnitude of the electromotive force, *N* is the number of loops in the coil, *Φ* is the magnetic flux, and *t* is time. Let’s set the coil’s normal to be directed out of the page. The total magnetic flux through the coil is given by

*Φ* = **B**1⋅**A**1 + **B**2⋅**A**2 = - *BA*1 + *BA*2, where **A**1 and **A**2 are the respective area vectors of the coil in the two magnetic fields.

As can be seen in the diagram below, d*A*1 = -*Lv*d*t* and d*A*2 = -*Lv*d*t*.



d*Φ*/d*t* = -*B*(d*A*1/d*t*) + *B*(d*A*2/d*t*) = -*B*(-*Lv*d*t*/d*t*) + *B*(*Lv*d*t*/d*t*) = 2*BLv*

Since *N* = 1, |*ε*| = 2*BLv* and *I* = |*ε*|/*R* = 2*BLv*/*R* = 2(2.00 T)(0.300 m)(5.00 m/s)/(5.00 Ω) = 1.20 A.

1. **Correct Response: A**

The fact that the gas molecules have a temperature means that it has a range of kinetic energies.