MCAT PHYSICS PREP

Sample Questions & Solutions

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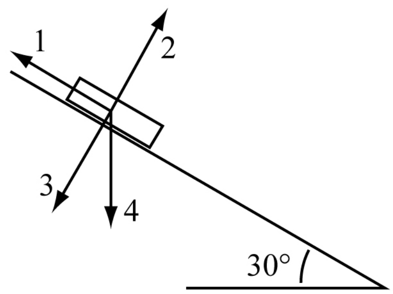
Passage I (Questions 1 – 2)

A book with a mass *m* sits on an incline that makes an angle of thirty degrees with the horizontal, as shown.



1. Which arrow represents the normal force?

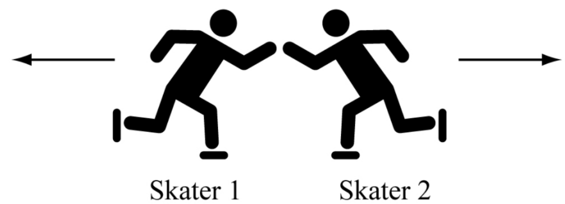
A. 1
B. 2
C. 3
D. 4

2. Which of the following formulae would you use to calculate the magnitude of the normal force, *N*?

A. $N = mg$
B. $N = mg\cos 30°$
C. $N = mg/\sin 30°$
D. $N = mg\sin 30°$

Passage II (Questions 3 – 4)

Skaters 1 and 2 are initially motionless on ice. They then push off of each other, Skater 1 has a mass of 50 kg, and travels to the left at a speed of 3.0 m/s. Skater 2 has a mass of 75 kg and travels to the right at an unknown speed. The friction is negligible.



3. With what speed does Skater 2 travel after they push off?

A. 1.0 m/s
B. 2.0 m/s
C. 3.3 m/s
D. 4.5 m/s

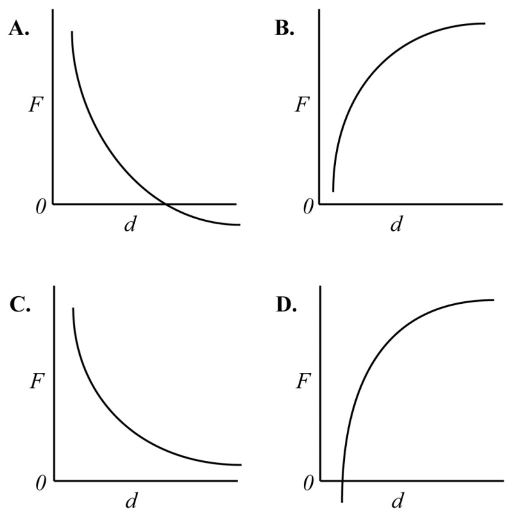
4. How much work in joules is done by Skater 2 on Skater 1 when they push off of each other?

A. 0 J
B. 10 J
C. 225 J
D. 10,500 J

Passage III (Questions 5 – 7)

Two point charges of charge Q_1 and Q_2 are slowly moved away from each other with varying distance *d*.

5. Which graph most closely shows the relationship between the electrostatic force *F* between them?



6. The charges are moved back to their original positions, and the electrostatic force between them is measured to be *F*. The charge on Q_1 is tripled, while the charge on Q_2 is left the same. What is the new force?

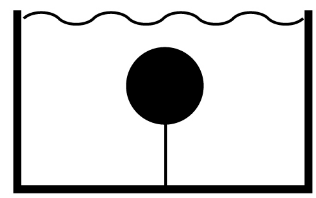
A. 3 *F*
B. 9 *F*
C. *F*
D. -*F*

7. The two charges are then moved so that the distance between them in increased by 3 times the original amount. What is the new force?

A. $1/3\ F$
B. $1/9\ F$
C. $3\ F$
D. $-9\ F$

Passage IV (Questions 8 – 10)

A 2.7 kg sphere with a volume of $4.5 \times 10^{-3}\,\text{m}^3$ is tied to the bottom of a container of water with a thin cord that doesn't stretch. The density of water is $1000\,\text{kg/m}^3$.



8. What is the tension in the cord in newtons?

A. -15 N
B. 0 N
C. 3.0 N
D. 18 N

9. If the cord is cut, what will be the acceleration of the sphere? Up is positive and down is negative.

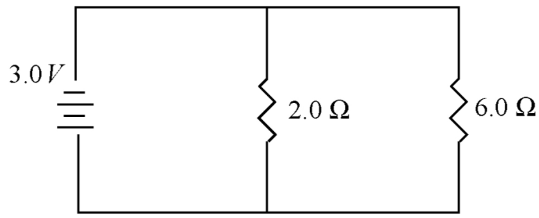
A. $-1.0\ \text{m/s}^2$
B. 0
C. $1.1\ \text{m/s}^2$
D. $6.7\ \text{m/s}^2$

10. The water in the container is now replaced with alcohol, which has a lower density than water. How would the tension in the uncut cord change, and how would the acceleration of the sphere upon cutting the cord change?

A. The tension and the acceleration would both increase.
B. The tension and the acceleration would both decrease.
C. The tension would increase and the acceleration would decrease.
D. Neither would change.

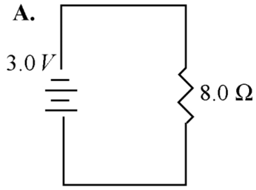
Passage V (Questions 11 – 13)

A simple electronic circuit is constructed as follows:

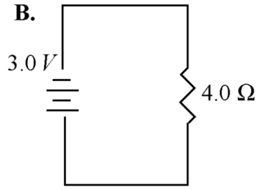


11. Which is the equivalent circuit?

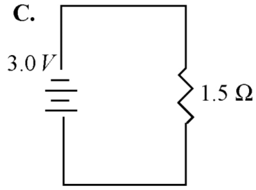
A.



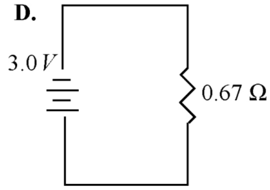
B.



C.



D.



12. What is the current in the circuit?

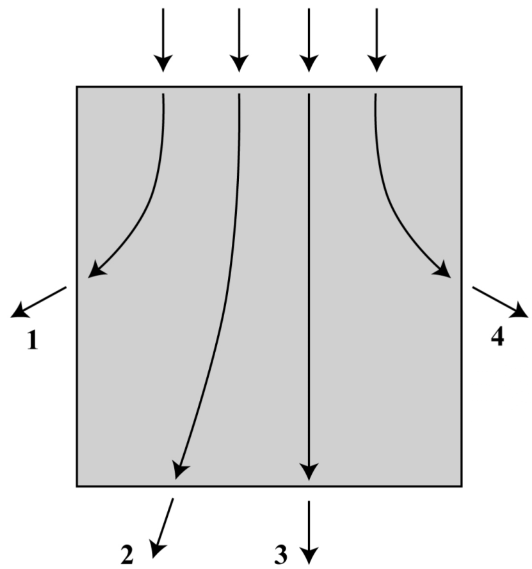
A. 0.37 A
B. 2.0 A
C. 0.75 A
D. 4.5 A

13. In the original circuit, what is the potential difference through the 6Ω resistor?

A. 3.0 V
B. 9.0 V
C. 1.0 V
D. 0.25 V

Passage VI (Questions 14 – 15)

Four particles travel (at the same speed) through a uniform magnetic field directed out of the page, as shown in the gray area of the diagram. The particles are an α-particle, a positron, a neutrino and an electron. Their paths are as shown.



14. Which path most likely belongs to the neutrino?

A. 1
B. 2
C. 3
D. 4

15. Which path most likely belongs to the positron?

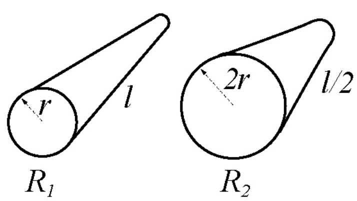
A. 1
B. 2
C. 3
D. 4

Questions 16 – 17 are independent of any passage and independent of each other.

16. A tensioned string has a transverse wave that is measured to move at 10 m/s, when the frequency is 500 Hz. What is the wavelength of the sound?

A. 0.02 m
B. 2 m
C. 50 m
D. 5000 m

17. Two conducting wires are as shown, the first has resistance R_1, radius *r* and length *l*. The second has resistance R_2, radius 2*r* and length $l/2$. What is the ratio of resistance R_1/R_2 ?



A. 1/8
B. 1
C. 2
D. 8

Answer Key

1. B
2. B
3. B
4. C
5. C
6. A
7. B
8. D
9. D
10. B
11. C
12. B
13. A
14. C
15. A
16. A
17. D

Solutions

1. B – There are different ways to remember which arrow represents the normal force. 'Normal' is a synonym for 'perpendicular,' at least to mathematicians. Simply pick the arrow that is perpendicular to the surface on which the object sits. The answer is B. (3 would be anti-perpendicular to the surface.)

Another way to remember is that the normal force is always the reactive force. The force that acts on the book is the gravitational force; which is always straight down. Now, the normal force for inclined problems is not reacting to the gravitational force, but to the component of the gravitational force that is perpendicular to the table, which would be 3. The force that reacts to 3, is thus 2, the normal force. Another way to think about this is that if the table was unable to supply sufficient normal force (i.e. if the table was made of thin tissue paper) then the book would break through the tissue paper and continue on its path through 4 and fall through to the floor.

2. B – All of the choices have the same units, so we can't eliminate any from units. But we can eliminate A because we know the force has to vary with angle, for instance if the table was vertical, it wouldn't be able to exert any force on the book, and the book would slide off and hit the floor.

At this point you could make a functional 50/50 guess between B and C. Or just remember that the $\sin(0°) = 0$, and then look at the problem. If the angle between the inclined plane and the horizontal were $0°$, then that would make choice C infinitely large (which is what happens to numbers when you try to divide them by zero). So choice C has to be wrong. We can also see that D is wrong, by using the same trick; if the angle is changed to zero, then $\sin 0° = 0$, and choice D would show a normal force of 0 too, which we know can't be right! This leaves B. OR, if we remember that $\cos 0° = 1$, then choice B would give $N = mg$ when the inclined plane is flat to the table, or $N = 0$ when the plane is 90° to the table, since $\cos 0° = 0$. This problem is a terrific reason why should remember the key trigonometric identities, there is strong chance that you'll need to use it at least once in the test.:

$$\boxed{\begin{array}{l}\cos 0° = 1 \ , \ \cos 90° = 0 \\ \sin 0° = 0 \ , \ \sin 90° = 1\end{array}}$$

When the problem writers make problems like this one, they're typically testing you on your ability to think in terms of limits. If you remember your undergraduate physics, it's also a pretty simple matter to just solve it directly with a quick sketch.

3. B – Momentum is always, always, always conserved, so the momenta of the combined skaters before they touch and after they touch has to be the same. This is because they start at rest, the magnitudes of their individual momenta after they separate must be equal (though in opposite directions). Hence, they *cancel out*. $\boxed{\text{momentum} = p = mv}$.

$$p_{\text{a}} = p_{\text{b}}$$
$$m_{\text{a}} v_{\text{a}} = m_{\text{b}} v_{\text{b}}$$
$$v_{\text{b}} = \frac{m_{\text{a}} v_{\text{a}}}{m_{\text{b}}} = \frac{50\,\text{kg}(3.0\,\text{m/s})}{75\,\text{kg}} = 2.0\,\text{m/s}.$$

Remember, you don't have a lot of time to do a lot of problems, so be careful not to spend time doing needless arithmetic. Notice that 3.0 cancels with 75 to make 1/25, and 50/25 = 2.

4. C – Remember that work is just the change in energy. Both work and energy have the same units (joules). This question essentially asks "how much energy was invested in Skater 1 by Skater 2?" Since both skaters were initially motionless, we just need to find the change in energy of one of the skaters. But which one?

The problem asks how much work is done on Skater 1, so use the mess and velocity for Skater 1 (note we use the minus since Skater 1 moves to the left, but it doesn't matter since the velocity is squared);

$$W = \Delta KE = \frac{1}{2} m_{\text{A}} v_{\text{A}}^2 = \frac{1}{2}(50\,\text{kg})(-3.0\,\text{m/s})^2 = 225\,\text{J}\,.$$

The answer is C.

Two things to note here … even if you used the mass and velocity for Skater 2, you would still come up with an answer closer to C than the others. And also give yourself a little pinch if you did the calculation on paper, because that burns through valuable time. You could just divide the 50 by 2, and note that $25 \times 9 = 225$.

5. C - Elimination would be a good, quick choice to solve this one. First, notice that A and D have points *below* the zero point of force, which suggests that the force would *reverse* at some point, for some reason. This has to be wrong, as Coulomb's Law describes the force on charges and there is no reason why it would suddenly change sign like that if the charges didn't change. It would also not change sign with varying distance. That leaves B and C. They both show *nonlinear* curves, that is, the lines aren't straight. That makes it a little harder. If one of the lines were straight, you would immediately know that it was the wrong one because Coulomb's Law says that the force between charges *is proportional to* or *varies with* the inverse square of the distance. "Inverse square" is a fancy way of the saying that the further two charges are from each other, the less force they have for each other, but that it decreases much more quickly than just inverse. You can see it in the equation for Coloumb's Law:

$$F = k\frac{Q_1Q_2}{r^2}.$$

r is on the bottom (inverse) and it is to the second power (squared). Since we now know that the force should *decrease* with increased distance between the charges, we see that choice C is the correct one.

6. A - Let's use Coulomb's Law, this is one of the formulas you will definitely need to remember. We'll do a before and after, with the before being the charges of Q_1 and Q_2 being as described in the Passage description, and $3Q_1$ and Q_2 being the new values described in the problem.

$$F_{\text{before}} = k\frac{Q_1Q_2}{r^2} \;\; ; \;\; F_{\text{after}} = k\frac{3Q_1Q_2}{r^2}.$$

Next, rewrite F_{after} like this:

$$F_{\text{after}} = 3\left(k\frac{Q_1Q_2}{r^2}\right),$$

and notice that what is inside the parenthesis is the same as $F_{\text{before.}}$, so that,

$$F_{\text{after}} = 3F_{\text{before}} = 3F.$$

Therefore, A is the answer.

7. B - Let's do it again with the before and after, but this time the value for *r* changes,

$$F_{\text{before}} = k\frac{Q_1Q_2}{r^2} \;\; ; \;\; F_{\text{after}} = k\frac{Q_1Q_2}{(3r)^2}.$$

And then reorder in the same way,

$$F_{\text{after}} = \frac{1}{9}\left(k\frac{Q_1Q_2}{r^2}\right) = \frac{1}{9}F_{\text{before}} = \frac{1}{9}F,$$

so that B is the answer.
Now, did you accidentally choose A? If so, you probably screwed up by being stingy with your parentheses. They're free, why be stingy? Due to trying to save a fraction of a second, you skipped the parens, and then you squared *r* but you didn't square 3. Major error, but it's a common error, many people make that error. The good news is that you made it on the practice problem, which means you won't need to make it on the real exam. Good dog! Sit! Stay! Roll over! You're being trained to take the MCAT Physics!

8. D – Buoyancy isn't too difficult, because you don't need to remember any formulas. Once you see remember the history of these problems they're easy. Here's the history … Archimedes, one of the first modern scientists, was hanging his super-intelligent self around ancient Greece, like 250 BC or so. He had some deep problem involving density of gold and it had him stumped, so as folks did back in those days, he went to the public Jacuzzi tubs, lowered himself in to get a soak and a think. He watched the water slosh over the side as other deep thinkers got in, and then he had his Eureka moment, at which point he supposedly ran through the streets naked screaming "Eureka!" The entire story may be fabricated, but it is just the kind of thing that an ancient physicist might do, they were an exhibitionist bunch.

Here's what he realized … a body in a fluid (and that fluid can be air or water or anything else) is *buoyed up by a force equal to the force of the mass that the body displaced.* You can use this concept for balls in water and helium balloons in air and submarines in vats of chocolate syrup. So for this problem, think of the sphere as making a "hole" in the water the same size and shape as the sphere. Then calculate the mass that the water in that hole would have had, multiply it by g (the acceleration due to gravity) to get the force, and remember that *that buoyant force is directed upward*, then add in the regular downward force due to the gravitational force of the ball, as if it wasn't in water at all. As long as you're careful with your signs (it's a force, which has magnitude and direction) then the sign of the force will tell you if it sinks or rises in the fluid. If it's negative (i.e. downward) then it sinks, if it's positive then it rises.

Oh yeah, I lied, there is one simple formula that you'll need to remember, but it's so commonly used that you'll use it everywhere, you might even use it as a doctor. That formula is just density and mass, and it's intuitive:

$$\text{mass} = \text{density} \times \text{volume}$$

$$\boxed{m = \rho V}.$$

If you forget that formula, you can figure it out in a second, by looking at the units for density, which were given to you in this problem, the units of $\text{density} = \text{kg/m}^3$, in other words the units of density (ρ) equal mass/volume, (the units of volume are m^3) same thing as that boxed density formula a few lines up, but just rearranged a little bit.

Okay, back to the buoyancy, that sphere is buoyed up by a force equal to the acceleration times the mass of the water it displaces,

$$F_{\text{buoyancy}} = m_{\text{water}} g = \left(\rho_{\text{water}} V_{\text{sphere}}\right) g$$

$$F_{\text{buoyancy}} = \left(1000 \frac{\text{kg}}{\text{m}^3}\right)\left(4.5 \times 10^{-3} \text{m}^3\right)\left(9.8 \,\text{m/s}^2\right)$$

$$F_{\text{buoyancy}} \simeq \left(1 \times 10^3 \frac{\text{kg}}{\text{m}^3}\right)\left(4.5 \times 10^{-3} \text{m}^3\right)\left(1 \times 10^1 \,\text{m/s}^2\right)$$

$$F_{\text{buoyancy}} \simeq 4.5 \times 10^1 \text{N}$$

$$F_{\text{buoyancy}} \simeq 45\text{N}.$$

Notice that to keep this thing computable in your noggin calculator, we used that $\simeq$ sign to show it's "approximately equal" since we replaced the 9.8 number with 10, which is close enough for the MCAT.

Now, what is the regular ol' downward gravitational force on the sphere, as if it wasn't even in water? (Remember, the minus sign because it's directing downward.)

$$F_{\text{gravity}} = -m_{\text{sphere}} g$$
$$F_{\text{gravity}} = -(2.7\,\text{kg})(9.8\,\text{m/s}^2)$$
$$F_{\text{gravity}} \simeq -27\text{N}$$

Add them together to get the total force …

$$F_{\text{total}} = 45\,\text{N} + (-27\,\text{N}) = 18\,\text{N}\,.$$

Which is up, the sphere pulls on the cord.

Whew! That was a bit of calculations, right? Remember, some problems are designed to suck up your time like a time vacuum! As you get better at these tests, you'll start to see which ones might do that. In this case, when you get the suspicion that it's a time-vacuum, you should perhaps skip it and save it for the end, when you've done the rest. If you don't have time to come back to it, remember to at least make a guess. As you get better, you'll actually be able to do problems like this in less than a minute. All of that explanation above was time-consuming in the explanation, but when you're used to it, you'll be able to do it quickly.

9. D – The cord keeps the sphere from moving in the liquid, but when the cord is cut, the sphere still experiences the same total force. So we just need to use $F = ma$ to find the acceleration;

$$F_{\text{total}} = m_{\text{sphere}} a$$
$$a = \frac{F_{\text{total}}}{m_{\text{sphere}}} = \frac{18\,\text{N}}{2.7\,\text{kg}} \simeq 6.5\,\text{m/s}^2$$

We estimated that last bit of math to save time, there was nothing else close to answer D, and that saved time over doing a division problem, albeit a fairly simple one.

10. B – The buoyant force is the only force that will change. The gravitational force would not change. We only need to notice that both the tension in the uncut cord and the acceleration of the sphere upon cutting the cord are both directly proportional to the buoyant force, which itself is directly proportional to the density of the liquid. Therefore, by lowering the density of the liquid, we also lower both the tension in the uncut cord and the acceleration of the sphere upon cutting the cord. The answer is B.

11. C - The circuit in the passage head is a Parallel Circuit. Parallel circuits add in inverses, and Serial Circuits add the regular way. So if you chose A, then your heart was in the right place, but you added the resistors as if they were in series, rather than parallel. Let's add them in inverses since the circuit is parallel;

$$\frac{1}{r_{\text{equiv}}} = \frac{1}{2\Omega} + \frac{1}{6\Omega},$$

$$\frac{1}{r_{\text{equiv}}} = \frac{3}{6} + \frac{1}{6} = \frac{4}{6} = \frac{2}{3} \quad \text{so,} \quad \frac{1}{r_{\text{equiv}}} = \frac{2}{3} \quad \text{and} \quad r_{\text{equiv}} = \frac{3}{2} = 1.5\Omega.$$

The answer is thus C. If you answered D, then you had the right idea, but you screwed up by not taking the inverse again, and didn't pay close enough attention to the formula.

12. B - The current is defined by Ohms Law, please remember it, easy formula, $V = IR$. (Some folks remember the formula as VIRus.) So,

$$I = V/R = 3\text{V}/1.5\Omega = 2\text{A},$$

the answer is B.

13. A - Here's a key bit of circuit knowledge to understand: In a series circuit, the current is the same at any point in the circuit, but the voltage requires the math cipherin'. In a parallel circuit, the current splits up at a point, and that requires the math to figure out for the different components, BUT, the voltage is the same at any point in the circuit. So, for this parallel circuit, the voltage is the same at all points, and it's just 3 Volts, choice A.

14. C - This one is simpler than it might seem, don't be thrown by an irrational fear of subatomic particles. First, do some Sesame Street logic, which of these things is not like the others? Which of these things is not the same? Yup, the particle on path 3 seems entirely unannoyed by that magnetic field, it goes into the field going straight, and it leaves the field without being diverted. Notice that the α-particle, the positron and the electron all have some kind of charge, while the neutrino has no charge, (and practically no mass). Now, remember that *charged particles that move through a magnetic field experience a force.* For this problem, you don't need to remember or know the Lorentz Force equation, the bit in italics is sufficient. Unlike the other three, a neutrino has no inherent charge, so it is undiverted in the magnetic field, and thus the answer is 3, or choice C.

15. A - This one is a tiny bit more difficult. You know it has to be either 1, 2, or 3. Again, apply some Sesame Street logic on the choices; a positron is basically a fancy-pants electron, only with an opposite charge from an electron. The electron has a negative charge, the positron has a positive charge. Both of them have tiny, tiny masses. The alpha-particle, on the other hand, is basically the nucleus of a helium atom, made of two protons and two neutrons. Since it has two protons, it has twice as much charge as the positron, but it also has much, much more mass than a positron. Since paths 1 and 4 are mirror images of each other, let's assume those are the electron and the positron, which leaves path 2 as the α-particle. But it asked us to find the positron particle, which we assume is either path 1 or path 4. Remember that the α-particle, and the positron both have positive charges, while the electron has a negative charge. Therefore, the positron should be deflected in the same direction as the alpha particle. That leaves us with Path 1, choice A.

16. A - If you know the formula for wavelength and frequency here, this is a simple problem. If you don't know it, Look at the units of the answers, they're all in units of meters. Use what is given to set up a formula test;

$$\frac{\text{m}}{\text{s}} \boxed{?} \text{ Hz} = \text{m}$$

What are the units of *Hz*? The units of Hertz are in *cycles per second*. What are the units of cycles? That's just a number, it's dimensionless, so the units [*Hz* = 1/s.] Rewrite …

$$\frac{\text{m}}{\text{s}} \boxed{?} \frac{1}{\text{s}} = \text{m}\,.$$

What would make that work? Our only choice is to flip the second unit term, so that,

$$\frac{\text{m}}{\text{s}} \frac{\text{s}}{1} = \text{m}\ .$$

Now we know the equation, it's the speed times the inverse of the frequency. That means,

$$(10\,\text{m/s})\left(\frac{1}{500\ \text{s}^{-1}}\right) = \boxed{0.02\,\text{m}}\,.$$

Now that you solved it by outlaw methods, you might choose to remember the formula;

$$\text{wavelength} = \frac{\text{wave velocity}}{\text{frequency}} \rightarrow \boxed{\lambda = \frac{v}{f}}\,.$$

17. D - First, can we use any special tricks to figure this one out? Can we find the formula from the answer choices? Any secret back doors? Nope, Nope, Nope. This one is set up as a ratio, which hides the magic. So, you now have a choice to make, do you skip this one or do you attempt it? If you remember the formula for resistivity from your formula cards, then go for it, because it's probably going to be simple, since it requires you to remember a slightly unusual equation. If you don't remember the formula, move along, citizen, go capture some other points.

For those who stayed, you may have remembered the simple formula for resistivity, which is another way of the saying "the conductor's personality with moving electrons around."

$$R = \rho\frac{l}{A} = \rho\frac{l}{\pi r^2},$$

where R is resistivity, ρ is a little constant that will either be given to you, or you won't need to remember it because it will cancel out (like this problem), l is the length of the wire and r is the radius of the wire. The first part of the equation uses A instead of the formula for the area of a cylindrical wire. Remember that one too, because your wire might be a bar or something not in the shape of a cylinder. Okay, let's write the two equations;

$$R_1 = \rho\frac{l}{\pi r^2}$$

$$R_2 = \rho\frac{l}{\pi r^2} = \rho\frac{l/2}{\pi(2r)^2}.$$

Let's simplify R_2 …

$$R_2 = \rho\frac{l/2}{\pi 4r^2} = \rho\frac{l}{8\pi r^2}.$$

Let's reorganize it a bit, so see how R_1 is hiding in there,

$$R_2 = \frac{1}{8}\left(\rho\frac{l}{\pi r^2}\right) = \frac{1}{8}R_1.$$

Careful! We're not done yet, and if you chose A, then you fell into a clever trap designed to screw up your score. They didn't ask for that resistivity, they asked for the *ratio*! Okay, so let's give them the ratio;

$$\frac{R_1}{R_2} = \frac{\rho\frac{l}{\pi r^2}}{\frac{1}{8}\left(\rho\frac{l}{\pi r^2}\right)} = \frac{1}{\frac{1}{8}} = 8.$$

So the answer is D. Be careful when you seem them ask for ratios. Alarm bells should go off in your head when you see that word. There is a reason why you are asked for them. One is to confuse you, but the other is to cancel things so that you get simple answers like this one, without needing to do a lot of calculations. Remember, the makes of this test aren't too interested in your ability to do basic math. If you are on a problem where you find yourself doing basic math, stop and think, you may have made a mistake.