McMaster University's Physics@Mac Online Physics Competition
November 27, 2014

General Statistics:

In this seventh competition, 760 teams from 51 different schools participated.

One team had a perfect score of 10. The average score was 4.

Students competed in two categories – Grade 11 or below, and Grade 12. Where there was a tie score, prize winners were determined by elapsed times. Virtually all teams completed the test in under 75 minutes and most finished in less than 60 minutes.

Cash prizes of $100 per team were awarded to the top three teams in Grade 12 and the top three teams in Grade 11 (or below). Certificates of Honourable Mention were awarded to teams in Grade 12 who achieved a score of at least 8 and teams in Grade 11 (or below) who achieved a score of at least 7.

Answer, success rate, statistics and solution for each question:

Question 1: Answer: A - 66% correct (B: 22%, C: 10%, D: 2%)

There are many different ways to estimate this, here is one:
The order of magnitude of the mass of the typical human is 100 kg. Humans are comprised of mostly carbon, hydrogen, oxygen, nitrogen, calcium and phosphorus. A reasonable estimate of the molar mass of a typical 'human' atom would be 10 g/mol (Pure Carbon would be 12 g/mol), which is equivalent to 0.01 kg/mol. One mole of material is 6.02×10^{23} atoms (Avogadro's number).

This yields 100 kg/0.01kg/mol = 10 000 moles for the typical human.
The number of atoms per human is 6.02×10^{23} atoms/mol *10 000 mol ~ 6×10^{27} atoms.
The closest answer is A: 10^{28}.

We can also check that answer B is not reasonable. In order to obtain an answer on the order of 10^{25}, the average molar mass would need to be 10 kg/mol, or the typical mass of a human 0.1 kg; both values are unreasonable.

Question 2: Answer: A - 30% correct (B: 19%, C: 30%, D: 21%)

We are used to thinking of lenses made of glass that are "immersed" in air, which has a lower index of refraction. Snell's Law then predicts that light rays bend toward the surface normal as they enter the lens, and away from the surface normal when they leave the lens. This makes a convex lens a converging lens and a concave lens a diverging lens.

In this question the lens is made of air, and it is immersed in water, which has a larger index of refraction. In this case, Snell's Law predicts that light rays bend away from the surface normal as they enter the lens, and towards the surface normal as they leave the lens. This make a concave lens a converging lens. As with any converging lens, the image of a distant object will be real and inverted.

Question 3: Answer: D – 19% correct (A: 35%, B: 30%, C: 16%)

The Work-Energy Theorem states that the net work done shows up as a change in kinetic energy (if friction is not present). In this question the mass begins at rest and ends at rest, so the net work done is zero. A detailed analysis shows that the work done by the spring is equal and opposite to the work done by gravity

Question 4: Answer C – 21% correct (A: 45%, B: 30%, D: 4%)

First notice that the top side of each bulb is at the same potential because they are connected by a wire.

Now consider if the switch is closed. If any current from the left hand current source flows through the left hand bulb, then the potential at the bottom of that bulb will be lower than the potential at the top. If any current from the right hand current source flows through the right hand bulb, then the potential at the bottom of that bulb will be higher than the potential at the top. Since the potentials at the top of the bulbs are the same, the potential at the bottom of the left bulb will be lower than the potential at the bottom of the right bulb. But these two points are connected when the switch is closed, which means that they must be the same potential. Therefore the original assumption that current flows through the bulbs is logically inconsistent. The only consistent result is that all the current flows around the outside of the circuit and none flows through the bulbs. This means that the bulbs are originally dark when the switch is closed.

Now open the switch. Now the potentials at the bottom of each bulb can be different, and current can flow through each bulb. The bulbs light up.

Question 5: Answer B - 21% correct (A: 17%, C: 14%, D: 47%)

The net force on an object is F=ma. All three masses will have the same acceleration because they are always in contact. We know block C has the smallest mass and therefore the smallest net force is required to produce this acceleration for block C. The net force is smallest on the middle block when the middle block is block C.

Question 6: Answer D – 24% correct (A: 3%, B: 68%, C: 5%)

The average speed is defined as the total distance divided by the total time. To cross the bridge, which has a total distance of 2 km, at an average speed of 60 km/h, would require a total time of 2 minutes. However, the car travels the first km up the bridge at 30 km/h,

which means that it already took 2 minutes to get to the top. There is no time left to travel the second half of the bridge!

Question 7: Answer: C – 64% correct (A: 2%, B: 31%, D: 3%)

The area under the graph starting at t = 0 up the some time t gives displacement since the start of the race to time t. At t = 4 seconds you and grandma have the same velocity, but you have covered a greater displacement compared to your grandma because the area under your curve is greater. At t = 14 seconds the area under grandma's curve will clearly be greater than that under your curve, so she will be far ahead. Of the choices given, t = 7 seconds is the most reasonable point at which the area under both curves is the same.

Question 8: Answer: D – 67% correct (A: 10%, B: 17%, C: 6%)

Since none of the masses are moving, the threads must support the weight of all the masses below them.
Upper threads: 3 threads must support 6 kg, or 2 kg/thread.
Middle threads: 2 threads must support 4 kg, or 2 kg/thread.
Lower threads: 1 thread must support 1 kg, or 1 kg/thread.
So the upper and middle threads are equally likely to break.

Question 9: Answer: B – 44% correct (A: 11%, C: 14%, D: 31%)

The slope of tangent of the position time graph gives the velocity at that time. At first the slope is zero and then becomes more negative. When the ball bounces, the velocity jumps to a positive value very quickly and then is reduced as the slope of the displacement curve becomes less steep, passes through zero at the top of the bounce, and then becomes negative again. This cycle then repeats.

Question 10: Answer B – 51% correct (A: 15%, C: 23%, D: 11%)

At the top of the loop the block is in contact with the track, so there must be a normal force on the block from the track. Since the track is on top of the block, the normal force must be down. There is also a force on the block due to gravity, which will also be down.