McMaster University's Physics@Mac Online Physics Competition
December 5, 2018

General Statistics:

In this eleventh competition, 877 teams from 86 different schools participated.

One team had a perfect score of 10. The average score was 3.5.

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. Almost every team 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: B – 59.4% correct (A: 6.0%, C: 19.0%, D: 13.3%, E: 2.2%)

The volume of a heart is roughly a liter. A heart pumps about 60 beats per minute. There are 60 min in an hour, 24 hours in a day, 365 days in a year and a lifetime is about 75 years. If we assume that during each heart beat a liter of blood goes through the heart, we can calculate that the heart pumps ~ $2x10^9$ liters of blood in a lifetime. The answer that is closest is B. We can also note that our estimate is probably a little bit larger than reality. It's probably a little less than a liter of blood per pump. A quick Google search confirms that heart pumps 200 million liters of blood in a lifetime (or 10^8 liters).

Question 2: Answer: E – 17.7% correct (A: 6.8%, B: 18.3%, C: 35.7%, D: 21.5%)

For Young's double slit experiment, we can use the relationship:

$$d\sin\theta = m\lambda$$

Where d is the separation between the fringes, θ is the fringe spacing (the separation between adjacent maxima on the screen), λ is the wavelength, and m is an integer. We wish to increase θ. The only way to do this would be to decrease d or increase λ. We could also increase the distance to the screen L.

Question 3: Answer: D – 30.9% correct (A: 59.8%, B: 4.7%, C: 2.5%, E: 2.1%)

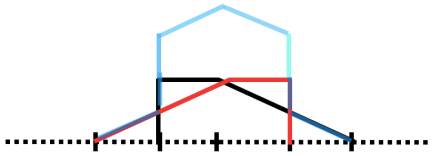
The impulse a car experiences is defined as the change in momentum which is also equal to the force multiplied by the time. If a car is travelling 50 km/h and then stops the impulse would be the same regardless of what caused the car to stop (a concrete wall or another car).

Question 4: Answer A – 50.1% correct (B: 24.8%, C: 13.8%, D: 5.8%, E: 5.5%)

A soda bottle behaves as an open-closed tube. The water acts as the closed end. The fundamental frequency of the bottle with a given amount of water is related to the amount of water in the bottle. More water corresponds to a smaller wavelength, λ, within the air and therefore a larger frequency, f, since the speed of sound, c, has not changed ($c=f\lambda$). Beat frequency is the absolute difference between the frequencies of the two sources. Initially a beat frequency of 4 Hz is heard meaning the frequency of the bottle could be either 444 Hz or 336 Hz since the tuning fork frequency is 440 Hz. We then add water and the beat frequency steadily increases to 5 Hz. This tells us that the initial frequency must have been 444 Hz and the final must have been 445 Hz. Adding water increases the frequency so the final frequency must be more than the initial and in order for the beat frequency to steadily increase it could not have been initially 336 and finally 445 as the beat frequency would have first decreased and then increased.

Question 5: Answer B – 40.3% correct (A: 21.9%, C: 10.4%, D: 17.0%, E: 10.3%)

The principle of superposition states that we add the amplitudes of wave pulses when they are interfering. In this question we will have constructive interference since the amplitudes are always positive. In the picture below the wave moving to the right is black, the wave moving to the left is red and the superposition of the two is drawn in blue:

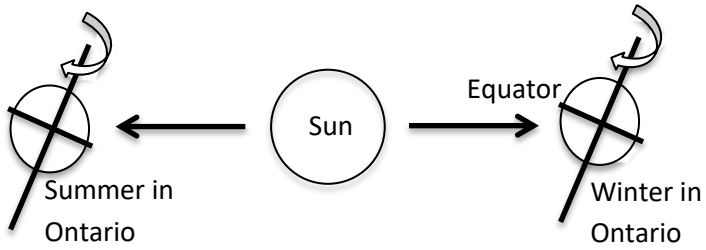


Question 6: Answer A – 27.9% correct (B: 9.6%, C: 16.6%, D: 6.3%, E: 39.5%)

We know that the rock gains an equal amount of momentum during each second because the impulse acting on the rock is equal to the force multiplied by the time. The force is constant (force of gravity) so for each second the impulse is constant. The impulse is also equal to the change in momentum.

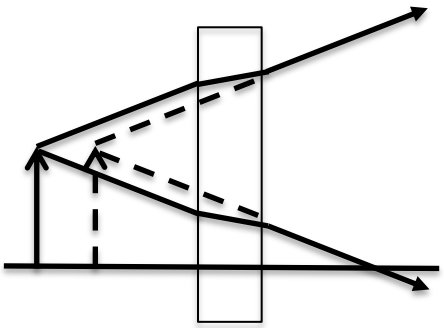
The rock will not gain an equal amount of kinetic energy during each second, it will gain an equal amount of kinetic energy during each meter it falls. We know this from conservation of energy – the increase in kinetic energy (not momentum) is equal to the decrease in gravitational potential energy. This also explains why it will not gain an equal amount of speed (or momentum) through each meter through which it falls.

Question 7: Answer: C – 29.3% correct (A: 35.0%, B: 17.2%, D: 0.4%, E: 18.1%)



The reason that there are seasons on the Earth is that the axis of rotation of the Earth is tilted with respect to the plane defined by its orbit around the Sun. This means that the axis is tilted away from the Sun in the winter in Ontario. This makes both the Sun shine more directly on the southern hemisphere, and the days shorter in the northern hemisphere. This is reversed in the Summer in Ontario, when the axis is tilted towards the Sun. On the first day of Spring or Autumn, the diagram would show the Earth either behind or in front of the Sun. Then the axis of rotation is still tilted, but not towards or away from the Sun. This makes the Sun shine directly on the Equator and the daylight and night portions of the day are the same everywhere on Earth.

Question 8: Answer: C – 16.8% correct (A: 28.2%, B: 11.4 %, D: 5.9%, E: 37.7%)



Since the glass surfaces are not curved, the glass does not act as a magnifying lens. When we draw two rays from the object arrow, both of them refract towards the normal when they pass into the glass, and then away from the normal when they exit the glass. The amount the angles change is exactly the same in each case since the changes in the indices of refraction are the same. This shifts the rays parallel to their original path, so that they appear to intersect closer to the glass pane, as viewed from outside the display box. However, they still intersect at the same height, so the object is not magnified. To convince yourself that the height doesn't change, draw the ray that leaves the object arrow and hits the glass perpendicular to its surface. It doesn't bend at all.

Question 9: Answer: B – 37.1% correct (A: 22.6%, C: 34.0%, D: 5%, E: 1.2%)

For a qualitative answer, the lowest resistance path (R+R= 2R) occurs when the switch is closed. For a constant battery voltage, this will give the largest current, so the light is brightest when the switch is closed.

For a quantitative answer, use the series and parallel resistance formulae. With the switch open, there are 2 parallel paths of resistance R+2R=3R. This gives an effective resistance of 1.5R. With the switch closed, the top two resistors are in parallel, and so are the bottom two. Each pair have an effective resistance of 2/3 R. These two pairs are now in series to give a total resistance of 4/3 R. This is a smaller resistance than when the switch is open, so the current is larger and the bulb is brighter.

Question 10: Answer E – 31.0% correct (A: 23.0%, B: 12.9%, C: 18.4%, D: 14.8)

Electric fields point in the direction that a positive charge would move. So the +Q charge would feel a force to the right and the -Q charge would feel the same force to the left. The net force would therefore be zero. The torque determines which direction the dipole will rotate. If the +Q has a force right and the -Q charge has a force left, the dipole will rotate in the clockwise direction.