McMaster University’s Physics@Mac Online Physics Competition
April 20, 2011

General Statistics:

In this third year of the competition, 341 teams (566 students) from thirty-four schools registered for the contest and 298 teams actually wrote the contest, some as teams of one, but most as teams of two. Of the teams who wrote, 3% were in grade 10 or below, 52% were in grade 11 and 45% were in grade 12.

No team had a perfect score of 10 and no team had a score of zero. The average score was 5.

Students competed in three categories – Grade 10 or below, Grade 11 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, the top three teams in Grade 11 and the top two teams in Grade 10 or below. Certificates of Honourable Mention were awarded to teams in Grade 12 who achieved a score of at least 8, teams in Grade 11 who achieved a score of at least 7 and teams in Grade 10 (or below) who achieved a score of at least 5.

Answer, Success Rate and Statistics for each Question:

Question 1: Answer A - 42% correct (B: 35%, C: 6%, D: 17%)

Charge cannot move about in an insulator, but it moves easily in a conductor like a metal. Even though the metal sphere in the question has no net charge, it contains large, precisely canceling amounts of positive and negative charge that can move about easily. When the insulating sphere with charge Q is brought close to the metal sphere, there is a Coulomb force between the charges in the two spheres. The charges in the metal sphere with the same sign as Q are repelled and shift to the far side of the metal sphere. Those of the opposite sign are attracted and shift to the near side of the metal sphere. Since the Coulomb force is stronger at closer distances, there is a net attractive force between the insulating sphere and the separated charge in the metal sphere, and they move towards each other. (A)

Question 2: Answer A - 19% correct (B: 29% C: 35%, D: 17%)

The definition of the focal length of a lens is the position at which parallel incoming light rays converge to form an image, or conversely, the position of an object from which the outgoing light rays are made parallel after passing through the lens. In this question, the object is placed at the focal point, so that the light rays leaving the lens are parallel. The parallel rays then hit the mirror and are reflected straight back – it doesn’t really matter what the distance between the
lens and mirror is. The returning parallel rays pass through the lens and focus to an image at the focal point - right on top of the object. Thus the image is also in front of the lens. (A)

Question 3: Answer B - 25% correct (A: 30%, C: 29%, D: 16%)

The volume of gasoline on the water will be the surface area of Lake Ontario times the thickness of the gasoline, which is given as one molecule of gasoline. Since the possible answers are different by three orders of magnitude, it is only necessary to estimate these quantities. It takes about 4 hours to drive from Hamilton to Kingston at 100 km/hour, so Lake Ontario is about 400 km long. The lake is quite skinny, so the width is about 100 km. This gives an area of $4 \times 10^4$ km$^2$, or $4 \times 10^{10}$ m$^2$ (the actual area is about one-half that, but no matter). A molecule of gasoline might be made up of 10 to 100 atoms, and the size of an atom is of order one Angstrom, or $10^{-10}$ m. Multiplying the area times thickness gives 40 to 400 m$^3$ for the amount of oil. This is closest to answer (B). To arrive at an estimate that is close to answer (A), for example, would require both being able to drive to Kingston in 24 minutes and that a molecule of gasoline is the size of a single hydrogen atom, both of which are clearly unreasonable. This shows that it is only necessary to make reasonable estimates for quantities you are not sure of.

Question 4: Answer B - 64% correct (A: 28%, C: 4%, D: 4%)

Newton’s third law states that the forces that two bodies exert on each other are equal in magnitude and opposite in direction, so answer (B) is correct. Intuitively, we know that we would rather be in the truck. The truck has a much larger mass than the car, so the equal forces will result in very different accelerations during the collision.

Question 5: Answer C - 62% correct (A: 12%, B: 8%, D: 18%)

The conservation of mechanical energy indicates that the final velocity (squared) only depends on the initial velocity (squared) and the original gravitational potential energy, or height of the tomato. Tomatoes Y and Z have the same initial velocity (squared) and initial height, so they must have the same final velocity as they hit the ground. Tomato X has zero initial velocity and an equivalent height. Its final velocity must therefore be smaller. (C)

Question 6: Answer C - 61% correct (A: 4%, B: 26%, D: 9%)

A graph of position vs. time for one dimensional motion has the shape of a parabola. The graphs of the two cars will be two different parabolas, and each time the parabolas intersect one of the cars will pass the other. It is easy to place two parabolas on a graph so that they intersect 0, 1 or 2 times, but 3 times does not happen. A more mathematical way to think of this is that the parabolas are quadratic equations (like $x=x_0+v_0t+1/2 at^2$). Setting the equations for two
parabolas equal, to solve for the points of intersection, will also be a quadratic equation. There are either 0, 1 or 2 real roots to a quadratic equation. (C)

Question 7: Answer B: 48% correct (A: 3%, C: 10%, D: 39%)

To a good approximation, the friction for a box sliding on a surface doesn't depend on the velocity, but rather on the coefficient of friction and the normal force of contact between the box and surface. According to Newton's second law, the force you push with is determined by the frictional force and the resulting acceleration of the box. Since the friction force is the same in both cases, and the acceleration is zero in both cases, the force you exert on the box is the same in both cases. (B)

Question 8: Answer D - 76% correct (A: 6%, B: 9%, C: 9%)

As the wheel turns about its axis, every point on the rim has the same speed and the same radius from the axis. Therefore, they all have the same centripetal acceleration. The wheel as a whole is not accelerating up or down or sideways, so there is no other acceleration to consider. (D)

Question 9: Answer D - 52% correct (A: 18%, B: 10%, C: 20%)

Although collisions are complicated in general, the elastic collision between a light and heavy object is straightforward. If you throw a ball at a truck, it will bounce back and the truck will not move. In this question, the heavy puck is not as massive as a truck, but the light puck will still bounce back, while the heavy one moves forward slowly. In the second collision, the heavy puck hits a light puck. The heavy puck will not bounce back, but will push the lighter puck in front of it. (D)

Question 10: Answer C - 47% correct (A: 25%, B: 18%, D: 10%)

To keep the force on the branch as small as possible, consider raising the pack at a slow, constant velocity, so that there is no acceleration. In the free body diagrams below, the pulley labeled "R" is rusty and the tension in the rope on one side of it is twice that on the other. The tension in the rope going to the pack is always equal to the weight mg of the pack. The tension in the rope holding up the top pulley is equal to the force pulling on the branch. This is smallest for the middle arrangement, or (C).