Multiple Choice Part There were 10 questions in a scrambled order. Here I list them using Roman Numerals, corresponding to the numbers they had in version A. For Versions B, C and D you will find the questions and answers in a different order.

I. Ignoring air resistance, if you drop an object, it accelerates downward at 10 m/s². If instead you throw it down, what will be its acceleration after you release it?
   a. Exactly 10 m/s² upwards
   b. Exactly 10 m/s² downwards [Correct]
   c. Less than 10 m/s² downwards
   d. More than 10 m/s² downwards
   e. It will have zero acceleration

After an object is released, and there are no longer any contact forces on it, it is a projectile in freefall. All objects in freefall have acceleration due to gravity downwards.

II. A 1000 kg car and a 2000 kg car are hoisted the same distance in a gas station. Raising the more massive car requires
   a. less work.
   b. the same amount of work.
   c. twice as much work. [Correct]
   d. four times as much work.
   e. more than 4 times as much work.

To hoist is to lift. The car moves upward because there is applied upward force. This force does work over the distance the car is moved, equal to the force times the distance. In each case the distance is the same. The force needed is that of the weight of the car, in order to cancel the downward pull of gravity. The 2000 kg car has twice as much weight, so it requires twice as much applied force, and twice as much work to lift it the same distance.

III. A TV set having a mass of 20 kg is at rest on a table. What is the force exerted by the table on the TV set?
   a. 20 kg.
   b. 20 N, upward.
   c. 200 N, upward. [Correct]
   d. 200 N, downward.
   e. 20 N, downward.

An object at rest must have zero net force on it. The force of gravity on the T.V. (weight) can be found from the equation F=mg, where g=10m/s². So F=20×10=200 N, downward. This downward pull of gravity must be cancelled by an equal but opposite upward force from the table on the T.V. This force is 200 N, upward.
IV. You weigh 800 Newtons. Your bicycle has a gear ratio set so that by pushing the pedal a distance of 0.1 metres (10 cm), the bicycle travels forward a distance of 1 metre (100 cm). If you put all of your weight down onto your pedal, what is the approximate forward force on the bicycle?
   a. 8 Newtons
   b. **80 Newtons** [Correct]
   c. 800 Newtons
   d. 8000 Newtons
   e. 80,000 Newtons

*The bicycle acts as a simple machine, which changes the distance over which a force is applied, while doing approximately the same amount of work. To solve, we will set \( F_p = \) force on pedal (equal to your weight, 800 N), \( d_p = \) distance the pedal moves (0.1 m), \( W_p = \) work done on pedal, \( F_b = \) force on bicycle (unknown), \( d_b = \) distance the bicycle travels (1 m), and \( W_b = \) work done on bicycle. By conservation of energy, the simple machine does not change the work, so we equate:
\[
W_p = W_b
\]
\[
F_p \times d_p = F_b \times d_b
\]
Solving for the unknown, \( F_b \):
\[
F_b = \frac{F_p \times d_p}{d_b} = \frac{800 \text{ N} \times 0.1 \text{ m}}{1 \text{ m}} = 80 \text{ N}
\]

V. A child pulls a wagon forward with a certain force. By Newton’s 3rd Law, the wagon pulls the child backward with an equal and opposite force [Correct always, even if the child and wagon are accelerating!]. One might argue that these two forces should cancel each other, and therefore neither the child nor the wagon should accelerate. What is wrong with such an argument?
   a. **The action-reaction pair forces are always exerted on different objects; therefore they cannot cancel each other.** [Correct]
   b. Newton’s 3rd Law does not apply to accelerating objects; it only applies to objects at rest or moving at a constant velocity in a straight line. [Incorrect: Newton’s 3rd Law does apply to accelerating objects.]
   c. There is no contradiction: the two forces do cancel each other, but the child and wagon accelerate anyway. [Incorrect: the force of the child on the wagon cannot cancel the force of the wagon on the child, since these two forces act upon different objects.]
   d. There is no contradiction: the two forces do cancel each other, therefore the child and wagon move with a constant velocity (zero acceleration). [Incorrect: the force of the child on the wagon cannot cancel the force of the wagon on the child, since these two forces act upon different objects.]
   e. The child is a living creature, so the force he pulls on the wagon is greater than the force of the wagon on the child. [Incorrect: The forces are equal and opposite, according to Newton’s 3rd Law.]

VI. In which of the following cases is the net force acting on a car \( (F_{\text{Net}}) \) equal to zero?
   a. The car is speeding up from 50 km/hr to 65 km/hr. [must be a forward net force]
   b. The car is slowing down from 65 km/hr to 55 km/hr. [must be a backward net force]
   c. The car is turning left at constant speed of 25 km/hr. [must be a net force to the left]
   d. The car is turning right while slowing down from 50 km/hr to 30 km/hr. [must be a net force with components both to the right and backwards]
   e. **None of these.** [Correct]
VII. Below is a sketch of a hammer which is being balanced upon a metal point, as shown by the black triangle. The darker part of the hammer is made of metal, and the white part of the hammer is made of wood. A dashed line is drawn to pass up from the metal point through the centre of mass of the hammer. Compare the mass of the part of the hammer to the left of the dashed line (mass on the left) to the mass of the part of the hammer to the right of the dashed line (mass on the right).

\[ \text{left} \quad \text{right} \]

a. The mass on the left is equal to the mass on the right.
b. The mass on the left is greater than the mass on the right.
c. **The mass on the left is less than the mass on the right.** [Correct]
d. All of the mass of the hammer is concentrated above the metal point; there is zero mass on the left and right.
e. It is impossible to compare the masses on left and right with the information given.

The torque of gravity on the right and left must be equal, so that they cancel one another and the hammer does not rotate. Torque = force \( \times \) moment arm. The moment arm on the centre of the handle to the left is greater than the moment arm on the centre of the hammer to the right. In order for the torques to be equal, the downward force on the handle to the left must be less than the downward force on the hammer to the right. The downward force is the weight, which is equal to the mass times the acceleration due to gravity. Since the weight of the handle to the left must be less, the mass must also be less.

VIII. The sketches show the outline of a car as seen from above. You can see the outer edge of the car, the exhaust pipe on the right, and the locations of the four wheels (dark rectangles). At the instant shown, the car is accelerating toward the left, as shown with the arrow labelled a. The car has rear-wheel drive, meaning the engine produces torque on the back wheels, but the front wheels are free to rotate. All four wheels roll without slipping while the car accelerates. Which set of arrows shows correctly the directions of the forces of friction of the road upon each of the wheels?

\[ \text{Correct sketch:} \]

The reason the back wheels rotate is because of the torque from the engine. If there was no friction, the bottom of the tires would slip backward, toward the right in the sketch. Static friction from the road prevents the tires from slipping by applying a forward force, toward the left in the sketch.

The reason the front wheels rotate is because of friction from the road (rolling without slipping). If there was no friction, the bottom of the tires would slip forward (no rotation), toward the left in the sketch. Static friction from the road causes the wheels to roll without slipping by applying a backward force, toward the right in the sketch.
IX. A cup of water is swung on a string in a large circle. As it is swinging, the water in the cup experiences an outward pull which keeps it in the cup. This is a fictitious force, which occurs because

a. the cup’s velocity is toward the centre of the circle and the water experiences a fictitious force in the direction opposite the cup’s velocity. [Incorrect: the cup’s velocity is always tangent to the circle, not inward.]

b. the cup is accelerating away from the centre of the circle and the water experiences a fictitious force in the direction of the cup’s acceleration. [Incorrect: the cup is accelerating inward, not outward.]

c. the cup is accelerating toward the centre of the circle and the water experiences a fictitious force in the direction opposite of the cup’s acceleration. [Correct.]

d. the cup’s velocity is away from the centre of the circle and the water experiences a fictitious force in the direction of the cup’s velocity. [Incorrect: the cup’s velocity is always tangent to the circle, not outward.]

e. the surface tension of water makes it cling to the bottom of the cup. [Surface tension is a small but real force, which has nothing to do with the swinging motion.]

X. Two balls are launched along a pair of tracks with equal velocities, as shown. Both balls reach the end of the track. Which ball reaches the end of the track first? (Neglect friction forces between the balls and the track.)

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A
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B
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a. A

b. B [Correct]

c. They reach the end of the track at the same time.

d. Without knowing the nature of the curved track, it is impossible to determine.

e. Only A can reach the end of the track; B cannot reach the end of the track.

As ball B falls, its speed increases, since its kinetic energy increases as the gravitational potential decreases. When ball B returns to the same height as ball A, it will be at the same speed again, but it will be advanced, and will reach the end of the track first. Note that on the downward part of the slope on the track, the normal force from the track has a component to the right. This will ensure that the horizontal component of ball B’s velocity must be increasing as it descends. Then the reverse force will occur on the way up, reducing the horizontal component of velocity back to its original value. The average horizontal speed must be greater for ball B than ball A.
Written Answer Part
There were 5 questions in a scrambled order. Here I list them using Roman Numerals, corresponding to the numbers they had in version A. For Versions B, C and D you will find the questions in a different order. Note that full points were only awarded for complete answers which showed work and the correct answer.

XI. (3 points) Briefly describe two different simple machines that might be used in everyday life. In each case, how does the machine affect the force, distance, and work?
The required reading for Class 3 mentioned many different types of simple machines, including the Lever, the Inclined Plane, the Wedge, the Screw, the Wheel and Axle, and the Pulley. In each case, you must mention how the machine helps us lift, pull, change the direction of the force or increase the force, while sometimes changing the distance over which this force is applied. A simple machine CANNOT increase the work done (it does not create energy).

XII. (3 points) When you push down on the handle of a nutcracker, its jaws pivot and crack a nut. If the point at which you push down on the handle is four times as far from the pivot as the point at which the jaws push on the nut, how much force will the jaws exert on the nut if you exert a force of 10 N on the handle? Please show your work and also fill in your final answer (with appropriate units!) in the box provided.
Both the handle and jaws sweep through the same angle, so the torque on each must be the same. The moment arm on the handle is 4 times greater. We know that torque = force × moment arm, so the force = torque / moment arm. If the moment arm is 4 times less on the jaws than on the handle, the force must be 4 times greater. 4 times 10 N = 40 N.

XIII. (2 points) Use the terms “momentum”, “force” and “impact time” to describe briefly why air-bags are important safety features in cars.
Before a collision, you and the car are moving forward at high speed. You both have a certain amount of momentum. Then the car stops suddenly, abruptly losing its momentum in its collision with a wall or other automobile. You must then have a collision in order to change your momentum. If you hit the steering wheel, your collision will have a short impact time, and therefore a large force in order to reduce your momentum. If you hit an air-bag, this will increase the impact time, decreasing the force needed to reduce your momentum by the same amount.
XIV. (3 points) You shoot an arrow straight up at 40 m/s. (a) How long after you shoot it will it run out of speed, and (b) how high will the arrow be when it runs out of speed? Please show your work and also fill in your final answers (with appropriate units!) in the boxes provided.

\[ a) \text{ change in } v = \text{acceleration } \times \text{ time. Solving for time, time} = \frac{(\text{change in } v)}{\text{acceleration}}. \text{ Since the arrow must go from 40 m/s to zero in order to reach its highest point and stop, the change in } v = 40 \text{ m/s}. \text{ The acceleration is that of gravity, } a = 10 \text{ m/s}^2. \text{ time} = \frac{40 \text{ m/s}}{10 \text{ m/s}^2} = 4 \text{ seconds.} \]

\[ b) \text{ distance traveled can be found from } d = \frac{1}{2} a \, \text{t}^2 = 0.5 \times 10 \text{ m/s}^2 \times (4 \text{ s})^2 = 80 \text{ m. Another way is to note that the average speed} = \frac{\text{final } + \text{ initial}}{2} = \frac{40 + 0}{2} = 20 \text{ m/s. The average speed} = \frac{\text{distance traveled}}{\text{time}}, \text{ so distance traveled} = \text{average speed } \times \text{ time} = 20 \text{ m/s } \times 4 \text{ s} = 80 \text{ m.} \]

(a) 4 s
(b) 80 m

XV. (2 points) A cyclist is riding forward on a level street. The centre of mass begins to tip the bicycle to the left. Briefly describe the most important effect which prevents the bicycle from continuing to tip to the left and falling over.

This was described in detail in the required reading for Class 7. The most important effect is dynamic stability, caused by the positive trail between the point where the steering axis intersects with the road and the point where the front wheel touches the road. This positive trail cause the front wheel to naturally turn left when the bicycle leans left. This causes the point where the front wheel touches the ground to suddenly move left as the bicycle rolls forward. Since the upper part of the bicycle does not suddenly move left, the bicycle straightens out and does not fall over.