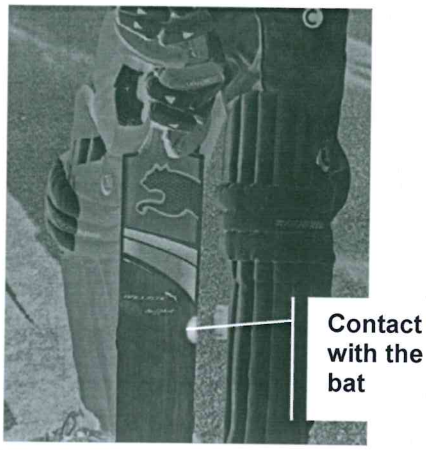
Solution 1

(16 Marks)



In cricket, a batsman is judged 'out' if the ball is caught after hitting the bat. The batsman is 'not out' if the ball is caught after hitting the batsman's leg. A cricket umpire must sometimes decide whether the ball hit the bat, the batsman's leg, or if both have been hit, which happened first. This can be tricky because the bat and the leg may be very close together, and the contact occurs over a very short time.

A technology called Hot Spot can be used to resolve this issue. Hot Spot is an infra-red imaging system, and is used to determine where, or what, the ball actually hit. There are two Hot Spot infra-red cameras, one at each end of the cricket ground. These measure and record the temperature of the bat and the batsman, before and after the ball makes contact. The infra-red images are then processed by a computer to show temperature differences between the 'before' and 'after' images.

The point is to show accurately whether the ball has hit the bat, the batsman's glove, the batsman's leg, or none of these. The black-and-white images produced by Hot Spot can potentially allow an umpire to precisely localise the ball's point of impact, and so reduce the risk of making an incorrect decision.

(a) Using the image above as a reference, which would have the higher temperature? (1 mark)

Circle the correct answer: a light part a dark part not enough information

Description	Marks
(a) The light part has the most energy and highest temperature	1
	Total 1

(b) Explain how the infra-red cameras are able to 'sense' where the contact or collision point has occurred. (2 marks)

Description	Marks
More infrared radiation comes out of the contact point than from the surroundings. Friction comes from collision → heat	1
The radiation travels to the sensor in the camera. Camera detects a change in temperature between the before and after image.	1
	Total 2

(c) The increase in heat energy of the contact point only lasts for a short time. Explain one form of heat transfer that is likely to occur in this situation. (3 marks)

Description	Marks
The spot is hotter than the surrounding environment and radiates this energy back into the cooler environment. Conduction to the rest of the bat + convection into the atmosphere also acceptable.	1
Radiation – radiates more energy than takes in from environment; Conduction – passes kinetic energy into the air or bat molecules through collisions; or Convection – heats the air making it less dense and rise to be replaced with cooler air	1-2
	Total 3

Solution 1 cont

(d) A 161 gram cricket ball moving at 25.0 m s^{-1} hits the edge of a stationary bat transferring 18.1 J of energy to the bat.

(i) Calculate the speed of the ball after the collision. (4 marks)

(ii) At the moment the photograph is taken, about 4 grams of wood absorb the 18.1 J of energy and increase in temperature. Estimate the temperature increase of this portion of the bat, given that the specific heat of the bat is 2.25×10^3 J kg^{-1} K^{-1}. Give your answer to an appropriate number of significant figures. (4 marks)

Description	Marks
(i) $\Delta E_k = \frac{1}{2} mv^2 - \frac{1}{2} mu^2$	1
$\frac{1}{2} mv^2 = \Delta E_k - \frac{1}{2} mu^2$ $v = \sqrt{[(\Delta E_k - \frac{1}{2} mu^2)/(\frac{1}{2} m)]}$	1
$v = \sqrt{[(18.1 - \frac{1}{2} \times 0.161 \times 25^2)/(\frac{1}{2} \times 0.161)]}$	1
v = 20.0 m s^{-1}	1
(ii) $Q = mc(T_f - T_i)$	1
$(T_f - T_i) = Q/mc$ $(T_f - T_i) = 18.1/(0.004 \times 2250)$	1
= 2.011111°C	1
= about 2°C given limiting sig figs	1
	Total 8

(e) After the ball is struck, it rolls along the ground and comes to a stop. Use Newton's Second Law to explain this. (2 marks)

Description	Marks
Newton's Second Law, F = ma, explains that an unbalanced force will result in an object changing its motion (acceleration)	1
The unbalanced force comes from the friction between the ball and the grass/ground, slowing the ball.	1
	Total 2

Solution 2

(3 marks)

Use the mathematical relationship (formula) for momentum to explain why a slow-moving train will generally have more momentum than a high-velocity small-calibre (diameter) rifle bullet. (Calculations are not required.)

Description	Marks
p = mv	1
The train's mass is billions of times bigger than the mass of the bullet. The bullet's velocity is only hundreds of times bigger than the train's That is, ratio $\frac{m_{train}}{m_{bullet}}$ >>>>>> ratio $\frac{v_{train}}{v_{bullet}}$	1–2
	Total 3

Solution 3

(4 marks)

Figures 1 and 2 show two types of crash barrier. The barrier in Figure 1 consists of metal posts that support horizontal metal cables. The posts break off easily at the base, and the cables are able to stretch. The barrier in Figure 2 consists of metal posts that support horizontal metal sheets. The posts are fixed strongly in the ground, and the metal sheets resist stretching.

Using your understanding of impulse and Newton's second law of motion, explain why the barrier in Figure 1 is more likely to reduce injury to the occupants of cars that drive off the road.

Description	Marks
$Ft = mv - mu$ OR Force × time = change in momentum	1
Value for change in momentum constant	1
If time of crash greater, force on passengers less	1–2
Total	**4**

Solution 4

(18 marks)

Melissa and Aidan are roller skating at the local park. Aidan, who has a mass of 80.0 kg, is skating at 5.00 m s^{-1} west toward Melissa. Melissa, with a mass of 55.0 kg, is stationary. After Aidan collides with Melissa, she moves away with a velocity of 3.40 m s^{-1} west.

(a) Name one physics quantity that will definitely be conserved in this situation. (1 mark)

Description	Marks
Momentum (or mass)	1
Total	**1**

(b) Calculate Aidan's momentum before the collision including correct units. (3 marks)

Description	Marks
$p = mv = 80 \times 5.0$	1
$p = 400$	1
kg m s^{-1}	1
Total	**3**

(c) Calculate Aidan's velocity (in metres per second) and direction after the collision. (5 marks)

Description	Marks
$p_i = p_f$	1
$400 + 0 = (55 \times 3.4) + (80 \times v)$ $400 = 187 + 80v$	1–2
$v = 2.66$ m s^{-1}	1
west	1
Total	**5**

(d) Consider the changes in kinetic energy before and after the collision.

(i) Calculate the total kinetic energy in joules before the collision. (3 marks)

Description	Marks
Melissa stationary so no kinetic energy	1
Aidan - $E_k = \frac{1}{2} mv^2 = 0.5 \times 80 \times 5^2$	1
$E_k = 1.00 \times 10^3$ J	1
Total	**3**

Solution 4 cont

(ii) Calculate the total kinetic energy in joules after the collision. (4 marks)

Description	Marks
Melissa: $E_k = 0.5 \times 55 \times 3.40^2 = 318$ J	1
Aidan: $E_k = 0.5 \times 80 \times 2.66^2 = 283$ J	1
$E_k = 318 + 283 = 601$ J	1
$E_k = 601$ J	1
Total	**4**

(iii) Considering your answers to (i) and (ii) above, explain how the law of conservation of energy applies to this collision. (2 marks)

Description	Marks
The change in kinetic energy is due to the initial kinetic energy being transformed into other forms of energy	1
Any numerical reference to the change in kinetic energy. For example, 399 J	1
Total	**2**

Solution 5

(6 marks)

A sudden and strong thunderstorm caused a 40.0 kg branch to break off a tree and fall from 9.00 m above the ground. The branch hit the roof of a house under the tree. Assume the branch was in free fall and the average height of the roof was 3.50 m above the ground.

(a) Calculate the speed of the branch when it hit the roof. (3 marks)

Description	Marks
$v^2 = u^2 + 2(a)s$	1
$= 0^2 + 2 \times 9.80 \times 5.50$	1
$v = 10.4 \text{ m s}^{-1}$	1
	Total 3

(b) The roof was strong enough to withstand the impact and the branch settled on the roof. If the impact contact time was 0.400 seconds, calculate the magnitude of the average force exerted on the roof during the impact. (3 marks)

Description	Marks
$Ft = \Delta p = m(v - u)$	1
$F = \dfrac{40.0(10.4 - 0)}{0.400}$	1
$F = 1040$ N	1
	Total 3

Solution 6

(16 marks)

A 1.55 kg remote control car is accelerated from rest. The car takes 5.66 s to reach its maximum speed of 14.2 m s^{-1}.

(a) (i) Calculate the acceleration of the car. (2 marks)

Description	Marks
a = (v-u)/t = (14.2-0)/5.66	1
= 2.51 m s^{-2}	1
Total	**2**

(ii) Determine the force needed to accelerate the car. (2 marks)

Description	Marks
F = ma = 1.55 × 2.51	1
= 3.89 N	1
Total	**2**

(b) Calculate the gain in the car's kinetic energy. Express your answer with appropriate units. (3 marks)

Description	Marks
$E_k = ½ mv^2 = 0.5 \times 1.55 \times 14.2^2$	1
= 156	1
J	1
Total	**3**

(c) Assuming no energy losses, calculate the power of the motor when travelling at its maximum speed. Express your answer with appropriate units. (3 marks)

Description	Marks
P = Fv = 3.89 × 14.2	1
= 55.2	1
W	1
Total	**3**

NOTE: allow 1 mark for $P = \dfrac{\frac{1}{2}mv^2}{t} = 27.6$

Sol (d) Despite the force due to the power output of the motor, the car is unable to go any faster. Explain why the remote control car has a top speed when considering its motion in real life. Use one of Newton's Laws to help your explanation. (3 marks)

Description	Marks
Names law; states forces are balanced; concludes no acceleration. For example: 1st Law; tend to stay in straight line uniform motion unless acted on by an unbalanced force; friction balances motor; or 2nd Law; F_{net} = 0 because friction force is equal and opposite to the motor's force; so a_{net}=0.	1–3
Total	**3**

Solution 6 cont

(e) The front of the remote control car has a soft, bendable bumper that is attached to the car with a spring. Apply your understanding of change of momentum to explain how the bumper keeps the car from becoming too badly damaged in a collision. (3 marks)

Description	Marks
Momentum change is constant (mv - mu = constant)	1
The bumper increases the time taken during a collision	1
F goes down when t increases (Ft = constant)	1
Total	**3**

Question 7

(18 marks)

(a) In steam locomotives, the energy from burning coal heats the water and converts it into steam. Using the kinetic theory of matter, explain the process involved in converting water into steam. (3 marks)

Description	Marks
Water (liquid phase) particles close together strong attractive forces	1
Adding heat increases vibration of particles	1
Particles move much further apart to become steam (gas phase)	1
Total	**3**

(b) Calculate the horsepower required to keep a train moving at 40 km h^{-1} if the engine provides a driving force of 1.45×10^5 N. Show **all** workings. (4 marks)

Description	**Marks**
40 / 3.6 = 11.1 m s^{-1}	1
P = Fv = $1.45 \times 10^5 \times 11.1 = 1611111$	1
P in horsepower = 522000 / 746	1
2.16×10^3	1
Total	**4**

(c) Calculate the momentum of an electric train travelling at 30.0 m s^{-1} (108 km h^{-1}). Include the correct units in your answer. Show **all** workings. (4 marks)

Description	Marks
$120 \times 1000 = 1.2 \times 10^5$ kg	1
p = mv = $1.2 \times 10^5 \times 30 = 3.60 \times 10^6$	1
Direction given, e.g. 'forward'	1
kg m s^{-1} or N s	1
Total	**4**

(d) The energy released when 240.0 kg of coal burns can power one 60 W lamp continuously for one year. Calculate the mass, in tonnes, of coal required to power five hundred (500), 60 W lamps for one year. Show **all** workings. (2 marks)

Description	Marks
500 × 240 = 120 000 (kg)	1
120 (tonnes)	1
Total	**2**

Question 7 cont

(e) When the two 120 tonne electric trains collided at the depot, Train A was travelling at 3.40 m s^{-1} north, while Train B was travelling at 2.20 m s^{-1} south. After the crash, Train B rebounded to be travelling at 3.00 m s^{-1} north. Assuming that momentum was conserved in this collision, calculate the speed, in metres per second, and the direction of Train A after the collision. Show **all** workings. (5 marks)

Description	Marks
Let north be positive south be negative $\Sigma p_i = \Sigma p_f$ $m_A u_A + m_B u_B = m_A v_A + m_B v_B$ $(120 \times 10^3 \times 3.40) + (120 \times 10^3 \times -2.20)$ $= (120 \times 10^3 \times v_A) + (120 \text{ x } 10^3 \times 3.00)$	1–2
$4.08 \times 10^5 - 2.64 \times 10^5 = 1.20 \times 10^5 v_A + 3.60 \times 10^5$	1
$V_A = -2.16 \times 10^5 \div 1.20 \times 10^5$ $= -1.80$ (full marks for 1.80)	1
south	1
Total	**5**

Solution 8

(3 marks)

Explain, using your understanding of one of Newton's laws, how the padding reduces injury to the batsman's leg if it is hit by a cricket ball.

Description	Marks
Relates to Newton's Second Law, Ft = mv - mu	1
Change in momentum, mv – mu, is constant	1
Padding increases the time over which the change in momentum occurs thus decreasing force on shin	1
Total	**3**