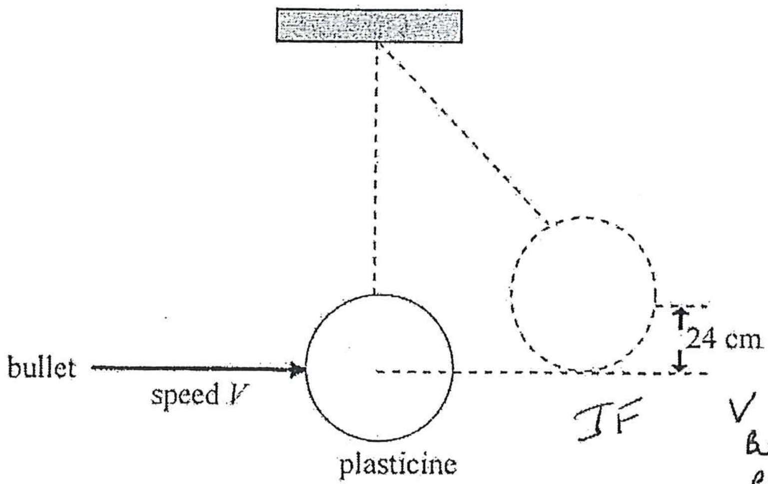
Question 21 **(13 marks)**

In a ballistics lab, the speed of a 5 gram bullet is determined by firing it into a 422 g piece of plasticine suspended on a string.



IF $V_{BULT\ PLAST} = 2.17 ms^{-1}$ = (2) MARKS.

It is found that after impact, the piece of plasticine with the embedded bullet rose 24 cm.

(a) Find the speed of the plasticine and bullet immediately after the impact. (3 marks)

FIND V_{BULLET} ONLY

$E_{K\ LOST} = E_{P\ GAINED}$

$\frac{1}{2} m_B v_B^2 = m_{TOT}\, g\, \Delta h$

$V_B = \sqrt{\frac{m_{TOT} \cdot g \cdot h}{\frac{1}{2} m_B}}$

$V = \sqrt{\frac{0.427 \times 9.8 \times 0.24}{0.5 \times 5 \times 10^{-3}}} = 20.04 ms^{-1}$ (1)

FOR V (TOTAL MASS)

$\Sigma p_i = \Sigma p_f$ (1)

$m_B V_B = m_{TOT} \cdot V_{TOT}$

$\therefore V_{TOT} = \frac{m_B \cdot V_B}{m_{TOT}}$

$= \frac{5 \times 10^{-3} \times 20.04}{0.427}$

$= 0.235 ms^{-1}$ (1)

(b) Find the speed of the bullet immediately before the impact. (3 marks)

AS ABOVE

$V_B = 20.04 ms^{-1}$

(c) Was the collision between the bullet and plasticine elastic or inelastic? Show calculations to support your answer. (3 marks)

INELASTIC (1) AS E_K IS NOT CONSERVED.

$E_{K\ BULLET} > E_{K\ BULLET + PLAST.}$

$E_{K(BULL)} = 0.5 \times 5 \times 10^{-3} \times (20.04)^2$
$= 1.045 J$ (1)

$E_{K(BULL+PLAST)} = 0.5 \times 0.427 \times (0.235)^2$
$= 0.01175 J$ (1)

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(d) A different bullet is fired from a different gun into a large block of wood. The block remains stationary after impact and the bullet melts completely. The temperature rise of the block is negligible. Use the following data to estimate the energy required to melt the bullet and hence estimate the minimum impact speed of the bullet.

(4 marks)

mass of bullet	6.2 g
specific heat capacity of the material of the bullet	130 $Jkg^{-1}K^{-1}$
latent heat of fusion of the material of the bullet	870 Jkg^{-1}
melting point of bullet material	330°C
initial temperature of bullet	30°C

ASSUME 100% ENERGY TRANSFER!

$\Delta E_k \Rightarrow Q = (mc\Delta t) + (mL_f)$ ①

330°C — Q = mLf

Δt = 300°C

30°C

FOR MIN ENERGY REQ. TO MELT BULLET

$Q = (6.2\times10^{-3} \times 130 \times 300) + (6.2\times10^{-3} \times 870)$ (241.8) (5.394)

$= 247.19$

$= 247$ J ①

NOW, FOR MINIMUM BULLET IMPACT SPEED

$\Delta E_k \Rightarrow Q$ (C.O)

$\therefore \frac{1}{2}mv^2 = 247.19$

$\therefore v = \sqrt{\frac{2Q}{m}}$ ①

$= \sqrt{\frac{2\times247.19}{6.2\times10^{-3}}}$

End of Section Two

$= \sqrt{7.9738\times10^{4}} = 282\ ms^{-1}$ ①

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SECTION THREE: Comprehension **20% (36 marks)**

This section has **one question.** Write your answers in the spaces provided.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time: 20 minutes.

Question 22 **(18 marks)**

Read the following article and then answer the questions that follow.

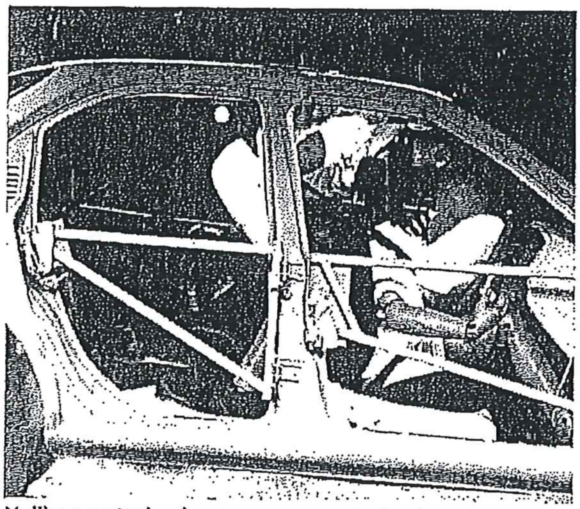
Car safety features

Article adapted from *Physics for the International Student*, 2010. IBN 9780170185134, pages 99-102.

Seatbelts

The seatbelt can be explained in terms of all three of Newton's laws. The most obvious is Newton's first law. In a front-on collision, the vehicle will come to a stop in a very short period of time. If an occupant is not wearing a seatbelt, Newton's first law states that their body will keep moving forward, even though the car has stopped. This causes the occupant to collide violently with objects in front of them. These objects could be the steering wheel, dashboard or, for rear seat occupants, the seats in front of them. If you are unrestrained and travel to the windscreen at 60 km/h, when the car comes to a stop, your skull bones are likely to collapse inwards by 2.1 cm. Your skull becomes the crumple zone. At 120 km/h, the crumple zone is likely to be more than 8 cm. These collisions often cause death or massive internal and head injuries with lifelong consequences.

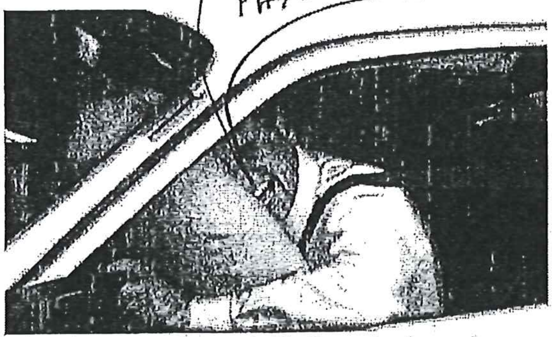
If seatbelts were to stop a person immediately, however, they would not prevent these injuries. This is where a knowledge and understanding of Newton's second law comes



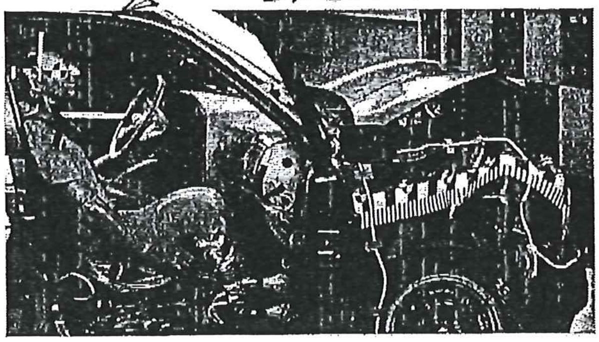
Unlike a restrained person, an unrestrained person continues at the impact speed until crumpling on impact with the window.

in. From the formula for Newton's second law, $a = F_{net}/m$, you will see that the force is directly proportional to the acceleration. So if the acceleration on the occupant's body can be reduced, the force on them can also be reduced. This is why seatbelts are not completely rigid. In fact, seatbelts are designed to stretch a little. This stretching effect is similar to a person landing on a mat instead of a hard floor when they jump from a height. It offers an element of 'cushioning' to the occupant. This cushioning means that in a front-on collision, the occupant's body will take a little more time to stop than if the seatbelt were rigid. This extra time reduces the acceleration on the occupant's body. This can be seen in the formula for average acceleration, $a_{av} = \Delta v/\Delta t$. If Δt is increased (the time taken for the body to stop), then a_{av} will decrease. If the acceleration is less, the force on the body will also be less. The seatbelt is also designed to be worn on the parts of the body that can withstand a greater force, such as the hips, chest and shoulders.

Air bags



Air bags were initially designed as an alternative to seatbelts in cars. They can easily be explained using Newton's second law. As with the seatbelt, if the acceleration of the occupant can be reduced, then so too can the force. Air bags increase the time it takes for a person to come to a stop in a collision. This means that the acceleration of the person is less. So, by Newton's second law of motion, the force on the person is also less. Air bags work best as a supplemental restraint system. This means that they work in combination with a seatbelt. Since the advent of the air bag, seatbelt usage in the United States has increased significantly. According to the National Highway Traffic Safety Administration, since the early 1980s, the rate of wearing seatbelts has risen from 14% to just over 80%.



Crumple zones

Crumple zones are areas at the front and rear of a vehicle that crumple in an accident to increase the stopping time. Again, they can be explained using Newton's second law. If the time taken to stop is increased, the acceleration is less and the force on the occupant is less. This can be seen in the formula for acceleration: $a_{av} = \Delta v \ \Delta t = F_{net}/m$ It used to be thought that the 'tougher' and stronger the car, the safer it was for the occupants. This is true in terms of the safety cell, the part of a car where the occupants are located. It is untrue, however, for the car as a whole. If the front of the vehicle collapses or crumples in a front-on collision, then the solid safety cell will take longer to stop.

(a) Seatbelts work by bringing your body to rest with the car. Explain why the injuries sustained are less for people wearing seatbelts. Be sure to use appropriate Physics outlined in the article. (4 marks)

- SEAT BELTS PREVENT/MINIMISE THE OCCUPANTS BODY HITTING THE COCKPIT/DASHBOARD. (1)
- THEY BRING THE OCCUPANT TO REST WITH THE CAR. (1)
- THE BELTS HAVE GIVE/SLACK WHICH INCREASES STOPPING TIME WHICH IN TURN REDUCES 'a' (1) AND REDUCES 'F'. (1)

$\downarrow a = \frac{\Delta v}{\uparrow t}$ AND $\downarrow F = ma \downarrow$

(b) The article states that an unrestrained person's head can be crushed by about 2 cm at 60 km/h but crushed by 4 times that amount when their car is travelling at twice the speed. Using appropriate Physics, suggest a reason for this. (2 marks)

WE ASSUME THAT CRUSHING FORCE IS CONSTANT.

$\Delta E_K = W = Fs$

- $\frac{1}{2} m v^2 = W = Fs$ (1)

$\frac{1}{2} m (2)^2 = W = F(4)s$

- CRUSHING DISTANCE (s) VARIES IN PROPORTION TO THE SQUARE OF THE HEADS IMPACT VELOCITY. (1)

(c) Racing car drivers wear a full racing harness, which is essentially a seatbelt with more straps that cross over each other. Suggest why this would reduce injury. (2 marks)

$\uparrow A$ (½) ONLY

FROM $\downarrow P = \frac{F}{A \uparrow}$

- MORE BELT CONTACT AREA REDUCES THE PRESSURE ON THE BODY (1)

OR

- MORE BELT AREA DISTRIBUTES THE LOAD ON THE BODY. (2)
- REDUCES THE CHANCE OF DRIVER SLIPPING OUT OF THE DIAGONAL "SASH" TYPE BELT. (1) ONLY.
- MORE SURFACE AREA (½) ONLY.

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NOW I_{CONST} ⇒ F_t = (↓F t↑)
NO BAG — AIRBAG

(d) Explain in terms of Newton's second law, how air bags reduce injury in a car accident. (2 marks)

(½)

• AIR BAGS INCREASE STOPPING TIME

i.e $\downarrow a = \frac{\Delta v}{\uparrow t}$ OR $\Delta p = \downarrow F t \uparrow$ (CONST)

• ACCELERATION IS REDUCED AND (½)

THUS, FROM $\downarrow F = ma \downarrow$, F IS REDUCED IF THE ACCELERATION IS REDUCED. (1)

(e) Air bags are designed to deflate immediately after they fill. Suggest why air bags are designed this way. (2 marks)

• DEFLATING AIR BAGS HAVE MORE 'GIVE' (1) / DECEL. SPACE

AND THEREFORE GIVES THE OCCUPANTS HEAD

MORE TIME TO DECELERATE. (1)

OR

• ALLOWS MORE DECELERATION SPACE

"LESS FORCE" ONLY ⇒ (½) MARK ONLY.

(f) The article states that airbags and seatbelts are designed to work together as a supplemental restraint system. Why do you think the two systems supplement each other so well? (2 marks)

TO AVOID NECK / SPINAL INJURY, IDEALLY

BOTH THE HEAD AND TORSO SHOULD

DECELERATE AT THE SAME RATE. (2)

• BOTH SEATBELTS AND AIR BAGS ~~RST~~ INCREASE STOPPING TIME (½) ONLY

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(g) The article explains the Physics behind crumple zones in terms of Newton's Laws. Explain how they reduce injury in terms of energy conservation and work done. (2 marks)

① • BUCKLING / BREAKING PANELS ABSORBS COLLISON ENERGY. i.e $\Delta E_k \Rightarrow W = F_s$ ① PANELS

• THE AMOUNT OF BUCKLING (s) AND THE IMPACT FORCE ON THE PANELS (F) IS PROPORTIONAL TO THE COLLISION ENERGY AND THUS WORK ON THE PANELS.

(h) Two cars of identical mass and velocity collide with a concrete wall. Car 1 has crumple zones built in and car 2 is very rigid. Describe any differences between the changes in momentum they experience. (2 marks)

② • BOTH CARS EXPERIENCE THE SAME CHANGE IN MOMENTUM. (Δp) # HOWEVER, THE TWO CARS WILL HAVE DIFF. RATES OF CHANGE.

• CAR ① WILL EXPERIENCE A LOWER ~~IMPULSE~~ IMPACT FORCE AS THE TIME TAKEN TO COME TO A HALT WILL BE LONGER.

End of Questions

i.e $\Delta p = Ft$

$\Delta p_{①} = \Delta p_{②}$

Additional Working Space

$\Delta p_{LOST} = \downarrow F t \uparrow$

NOTE: MOST STUDENTS DID NOT ANSWER THE QUESTION i.e THEY DID NOT TALK ABOUT THE DIFFERENCES ~~BETWEEN~~ OF MOMENTUM BETWEEN CAR ① AND ②.

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