Problem Set 17: Momentum and Impulse

17.1 $p = mv = (64kg)(9.5ms^{-1}) = 608\ kgms^{-1}$ North (or 608 Ns North)

17.2 $36\ km\ h^{-1} = \left(\frac{36}{3.6}\right) = 10\ ms^{-1}$

$p = mv = (2100kg + 55kg + 45kg)(10ms^{-1}) = 22{,}000\ kgms^{-1}$ West (or 22,000 Ns West)

17.3 [a] $v = \frac{p}{m} = \frac{8kgms^{-1}South}{75kg} = 0.107\ ms^{-1}$ South

[b] $v = \frac{p}{m} = \frac{8kgms^{-1}\ South}{0.5kg} = 16\ ms^{-1}$ South

17.4 [a] Impulse = $Ft = (63N)(0.1s) = 6.3\ Ns$ in the direction of the bat's velocity

[b] Let "toward the cushion" be positive

Then $p_{initial} = mu = (0.2kg)(1.25ms^{-1}) = 0.25\ kgms^{-1}$

$p_{final} = mv = (0.2kg)(-1.25ms^{-1}) = -0.25\ kgms^{-1}$

Impulse = $\Delta p = -0.25kgms^{-1} - 0.25kgms^{-1} = -0.50\ kgms^{-1}$ (away from the cushion)

[c] $80\ km\ h^{-1} = \left(\frac{80}{3.6}\right) = 22.2\ ms^{-1}$

$p_{initial} = mu = (18500 + 4250)kg \times 22.2ms^{-1} = 5.06\times10^5\ kgms^{-1}$

$p_{final} = 0$

Impulse = $\Delta p = -0\ kgms^{-1} - 5.05\times10^5kgms^{-1} = -5.06\times10^5kgms^{-1}$ (negative means opposite direction of travel)

[d] Impulse = $Ft = (150N)(4s) = 600\ Ns$ East

17.5 $F = \frac{impulse}{time} = \frac{195N}{13s} = 15.0\ N$

17.6 $\Delta v = \frac{Ft}{m} = \frac{(-810N)(2.5s)}{250kg} = -8.1\ ms^{-1}$

$\Delta v = v - u$

So $v = \Delta v + u = -8.1ms^{-1} + 16.5ms^{-1} = 8.4\ ms^{-1}$ (positive means in the original direction)

17.7 [a] $p_{initial} = mv = (0.15kg)(7ms^{-1}) = 1.05\ kgms^{-1}$ towards Sam

[b] $p_{final} = 0$

Impulse = $\Delta p = -0 - 1.05kgms^{-1} = -1.05\ kgms^{-1}$ (towards Max)

17.8 [a] $m_1u_1 + m_2u_2 = (m_1 + m_2)v$

Since $u_2 = 0$, then

$v = \frac{m_1u_1}{(m_1+m_2)} = \frac{(0.12kg)(30ms^{-1})}{0.12kg+0.1kg} = 16.4\ ms^{-1}$ (in original direction)

[b] $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Since $u_2 = 0$, then

$v_2 = \frac{m_1u_1 - m_1v_1}{m_2} = \frac{(0.12kg)(30ms^{-1})-(0.12kg)(15ms^{-1})}{0.1kg} = 18\ ms^{-1}$ (in the original direction)

17.9 [a] Impulse – momentum equation states that $F = \frac{m(v-u)}{t}$

So, if the time taken to stop is short, the force is larger, hence a greater impact on joints and muscles.

[b] $m_{club}u_{club} + m_{ball}u_{ball} = m_{club}v_{club} + m_{ball}v_{ball}$

Since $u_{ball} = 0$ and you cannot control speed of golf club after impact, then the following can be used to influence the ball speed:

- Speed of golf club head (length of club), u_{club}
- Mass of golf club head, m_{club}

Increasing both factors will increase the final speed of the golf ball.

Also since $F = \frac{m(v-u)}{t}$, then following through with your swing lengthens the time, t with which the ball is in contact with club which will also produce a greater change in velocity.

[c] Same explanation as part [b].

[d] Tightly strung racquets have less elasticity than others so on impact with the tennis ball, the stopping time for the ball (before it is sent in the opposite direction) will be reduced. Since $F = \frac{m(v-u)}{t}$, then the racquet itself will impose a greater force on the ball, making the ball move faster.

[e] Since $F = \frac{m(v-u)}{t}$, then if the time is longer (gradual stop) the force on his hands will be reduced.

[f] As part [e]; however, now time is important to extending the “catching” time may mean missing an opportunity. Also, all the catchers have special gloves, and a baseball is softer than a cricket ball.

17.10 [a] Newton's first law states that a moving body will keep moving unless an external force accelerates it. A person in a car needs a restraining force, such as that provided by a seatbelt, in the event that a vehicle suddenly stops. Otherwise, the person would continue moving in the original direction of the vehicle and then suffer injury when accelerated rapidly by the windscreen or some other very solid object.

[b] Since $F - \frac{m(v-u)}{t}$, then if the time is longer (gradual stop) the force on a human torso will be reduced – a collapsible steering wheel provides such a gradual stop.

[c] Same explanation as part [b]

[d] Same explanation as part [a]

[e] Same explanation as part [b]

17.11 [a] Impulse $= Ft = (48N)(0.002s) = 0.096\ Ns$

$$F = \frac{impulse}{time} = \frac{0.096Ns}{0.080s} = 1.2\ N$$

[b] Since $F = \frac{m(v-u)}{t}$, then if the time is longer (gradual stop) the force on a human torso and head will be reduced – an air bag provides such a gradual stop.

17.12 [a] $v = \sqrt{2gs} = \sqrt{(2)(9.8ms^{-2})(20m)} = 19.8\ ms^{-1}$

[b] $a = \frac{v^2 - u^2}{2s} = \frac{(0 - 19.8ms^{-1})^2}{(2)(0.03m)} = -6530\ ms^{-2}$

[c] $F = ma = (1.5kg)(-6530ms^{-2}) = -9800\ N$

[d] $t = \frac{v-u}{a} = \frac{0-19.8ms^{-1}}{-6530ms^{-2}} = 3.03\times10^{-3}s$ (or 3.03 ms)

[e] Impulse $= Ft = (9800N)(0.00303s) = 29.7\ Ns$

[f] Impulse $= \Delta p$, so the change in momentum = 29.7 $kgms^{-1}$ (or 29.7 Ns)

17.13 Since $F = \frac{m(v-u)}{t}$, then in an accident when a car and driver may be instantly brought to rest (hence a very short time, t) the force of impact on the belt could be huge. It does not just depend on the person's mass (or their weight).

17.14 $mu = m_1v_1 + m_2v_2$

So $v_2 = \frac{mu - m_1v_1}{m_2} = \frac{(800kg)(500ms^{-1})-(240kg)(-120ms^{-1})}{560kg} = 766\ ms^{-1}$ (in the spacecraft's original direction).

17.15 [a] $p_{shell} = mv = (10kg)(75ms^{-1}) = 750\ kgms^{-1}$ forward

[b] Zero

[c] Zero

[d] $p_{shell} + p_{cannon} = 0$

So $750kgms^{-1} = -mv$

$v = -\frac{750kgms^{-1}}{5000kg} = -0.15\ ms^{-1}$ (backwards)

17.16

$m_1u_1 + m_2u_2 = (m_1 + m_2)v$

Since u_2 = zero, then $u_1 = \frac{(m_1+m_2)(v)}{m_1}$

She can then determine m_1 and m_2 using a balance and she can calculate v by timing how long it takes (t) a block of wood with the embedded bullet to travel a specified distance (s) after impact, then $v = \frac{s}{t}$

17.17

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Since u_2 = zero, then

$v_2 = \frac{m_1u_1 - m_1v_1}{m_2} = \frac{(4kg)(2.5ms^{-1})-(4kg)(1.4ms^{-1})}{0.5kg} = 8.8\ ms^{-1}$ (in the original direction)

17.18

$(m_1 + m_2)u_1 + m_3u_3 = (m_1 + m_2 + m_3)v$

Then

$v = \frac{(m_1+m_2)u_1+m_3u_3}{m_1+m_2+m_3} = \frac{(40kg+50kg)(2.0ms^{-1})+(45kg)(5.0ms^{-1})}{(40+50+45)kg} = 3.0\ ms^{-1}$ West

17.19

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$(4200kg)(2ms^{-1}) + (2500kg)(1.5ms^{-1}) = (4200kg)v_1 + (2500kg)(3ms^{-1})$

Gives $v_1 = 1.11\ ms^{-1}$ in the original direction

17.20

Initially, $p_x = musin\theta = (0.02kg)(500ms^{-1})(sin45°) = 7.07\ kgms^{-1}$

And $p_y = mucos\theta = (0.02kg)(500ms^{-1})(cos45°) = 7.07\ kgms^{-1}$

Finally, $p_x = mvsin\theta = (0.02kg)(500ms^{-1})(sin45°) = 7.07\ kgms^{-1}$

And $p_y = mvcos\theta = (0.02kg)(500ms^{-1})(cos45°) = -7.07\ kgms^{-1}$

$\Delta p_x = 7.07\ kgms^{-1} - 7.07\ kgms^{-1} = 0$

$\Delta p_y = -7.07\ kgms^{-1} - 7.07\ kgms^{-1} = -14.14\ kgms^{-1}$

$\Delta p = -14.14\ kgms^{-1}$

17.21 [a] $m_1u_1 + m_2u_2 = m_1v + m_2(2v)$

$(0.08kg)(12ms^{-1}) - (0.06kg)(14ms^{-1}) = (0.08kg)v + (0.06kg)(2v)$

Gives v = 0.60 ms^{-1} in the original direction of Walter's ball (ball 1)

So Walter's ball moves at 0.60 ms^{-1} in its original direction

And Linda's ball moved at 1.20 ms^{-1} in the opposite direction to its original motion

[b] $m_1u_1 + m_2u_2 = m_1v + m_2(2v)$

$(0.08kg)(12ms^{-1}) - (0.06kg)(14ms^{-1}) = -(0.08kg)v + (0.06kg)(2v)$

Gives v = 3.0 ms^{-1} in the original direction of Walter's ball (ball 1)

So Walter's ball moves at 3.0 ms^{-1} in the opposite direction to its original motion

And Linda's ball moves at 6.0 ms^{-1} in the opposite direction to its original motion

17.22 $Ft = m\Delta v$

For first carriage, m_1 : $Ft = (m_1)(4ms^{-1})$ and for second carriage, m_2:

$Ft = (m_2)(6ms^{-1})$

Now, $Ft = (m_1 + m_2)v$

So $Ft = \left(\frac{Ft}{4ms^{-1}} + \frac{Ft}{6ms^{-1}}\right)v$

Then Ft cancels, leaving $v = \frac{12}{5} = 2.4\ ms^{-1}$