MONASH University
School of Physics

FIRST YEAR PHYSICS - SELF-DIAGNOSIS EXERCISES

Mechanics - 3. Momentum

(for PHS1011/ENG1802)

W.A. Rachinger, G.L. Hua, D.R. Mills ©

1. Imagine a rather artificial situation in which you strike a ball and exert a constant force F for a short period Δt. The product $F\Delta t$,called the impulse, is a measure of how long and how hard you hit the ball.

   The magnitude of the Impulse $F\Delta t$ is most closely related to:

   A. The acceleration of the ball
   B The change in direction of motion of the ball
   C The change in kinetic energy of the ball
   D The change in momentum of the ball

   Give your reasons why the other answers are incorrect.

2. Consider an object of mass 2 kg initially at rest which is acted on by a constant force of 15 N for a period of 2 s.

   (a) What is the impulse of this force?

   (b) What is the speed of the object at the end of the 2 s period?

3. Consider an object of mass 2 kg "colliding" (i.e. interacting) with a device which exerts a constant force of 20 N on it for a period of 4 s.

   (a) What is the magnitude of the impulse of this force?

   (b) If the initial velocity of the object was +50 m s^{-1} and the force was negative (i.e.in the direction opposite to the initial direction of motion), what is the velocity of the object after the collision?

   (c) If the initial velocity of the object was +15 ms^{-1} and the force was in the direction opposite to the initial direction of motion, what is the velocity of the object after the collision?

Answers

1. D. This follows from the relation $F\Delta t = m(v_f - v_i)$, where v_i and v_f are the initial and final velocities respectively and the product mv defines momentum.

   A is incorrect since the acceleration a at any instant is determined by the instantaneous value of F only via Newton's Second Law $F = ma$.

   B is incorrect. When an impulse acts on the ball the direction of motion is not necessarily changed, for example when a ball is caught.

   C is incorrect. Although a change in kinetic energy is often associated with an impulse this is not necessarily the case. An example is a ball rebounding from a wall, striking the wall with a velocity +v and leaving the wall with a velocity -v. In this case the kinetic energy ($= \frac{1}{2}mv^2$) is unchanged.

2. (a) The magnitude of the impulse is $F\Delta t = 30$ N s $= 30$ kg m s^{-1}.
   Note the alternative but equivalent form of units, N s corresponding to force × time and kg m s^{-1} corresponding to mass × velocity i.e. momentum.

   (b) 15 m s^{-1}. The impulse of 30 N s causes a change in momentum $m(v_f - v_i)$, where v_i and v_f are the initial and final velocities respectively.
   Thus $30 = 2(v_f - 0)$ and $v_f = 15$ m s^{-1}.

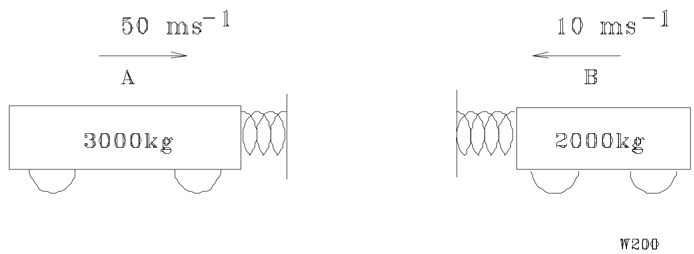
3. (a) The magnitude of the impulse is $F\Delta t = 80$ N s $= 80$ kg m s^{-1}.
   Note the alternative but equivalent form of units, N s corresponding to force × time and kg m s^{-1} corresponding to mass × velocity i.e. momentum.
   Note that the word "interaction" was used as an alternative to "collision". It is not necessary that a "collision" should be a short sharp process. The "collision" of a space craft with a planet may involve only a spell in the planet's gravitational field and not a crash on the planet's surface.

   (b) +10 m s^{-1}. The impulse is -80 N s and this causes a change in momentum $m(v_f - v_i)$, where v_i and v_f are the initial and final velocities respectively.
   Thus $-80 = 2(v_f - 50)$ and $v_f = +10$ m s^{-1}.
   Here the impulse has opposed the motion and slowed down the ball.

   (c) -25 m s^{-1}. The impulse of -80 N s causes a change in momentum $m(v_f - v_i)$.
   Thus $-80 = 2(v_f - 15)$ and $v_f = -25$ m s^{-1}.
   Here the impulse has opposed the motion and caused the ball to reverse its direction of motion and leave the device with an increased speed.

Questions

4.



Two railway trucks A and B equipped with spring buffers collide. The masses `and velocities of the trucks are as shown in the diagram.

(a) At the first instant of collision the magnitude of force exerted by truck A on truck B will be ....(greater than, less than, equal to) the magnitude of the force exerted by truck B on truck A.

(b) At later times during the collision the magnitude of the force exerted by truck A on truck B will be ....(greater than, less than, equal to) the magnitude of the force exerted by truck B on truck A.

(c) The magnitude of the impulse on A during the whole collision process will be ....(greater than, less than, equal to) the magnitude of the impulse on B.

(d) What is the momentum of truck A before the collision?

(e) What is the momentum of truck B before the collision?

(f) What is the total momentum of the system before the collision?

(g) The ratio

$$\frac{\text{Total momentum of system before collision}}{\text{Total momentum of system after collision}}$$

is: (One or more answers)

A equal to 1 only if the collision is elastic
B always less than 1
C greater than, equal to or less than 1 depending on how much mechanical energy is lost in the collision.
D always equal to 1
E equal to zero if the trucks lock together during collision
F equal to or less than 1 depending on how much mechanical energy is lost in the collision.

Answers

4. (a) Equal to. This follows from Newton's Third Law. The force which body A exerts on body B is equal to that exerted by body B on body A.

   (b) Equal to. Newton's Third Law is always true. At any time the force which body A exerts on body B is equal to that exerted by body B on body A.

   (c) Equal to. Since the magnitude of the forces are equal at any instant, the magnitude of the impulses $F.\Delta t$ during any time interval Δt will be equal. Hence the magnitude of the impulses over any extended time period will be equal.

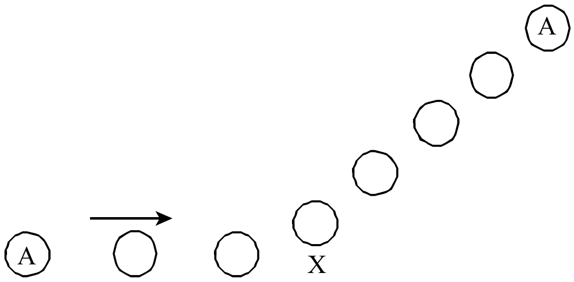
   (d) 1.5×10^5 kg m s^{-1} to the right.
   Momentum = mass × velocity = 3000 kg × 50 ms^{-1}.

   (e) 2×10^4 kg m s^{-1} to the left.
   Momentum = mass × velocity = 2000 kg × 10 ms^{-1}.

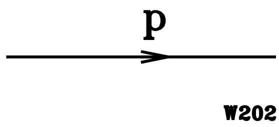
   (f) 1.3×10^5 kg m s^{-1} to the right.

   (g) D. Momentum is always conserved in a collision, provided that there are no external forces acting. Since the internal forces are equal and opposite {questions (a) and (b)} the impulses are equal and opposite {question (c)} and hence the change in momentum of each of the trucks are equal and opposite. Although mechanical energy may be lost in a collision, momentum is always conserved.

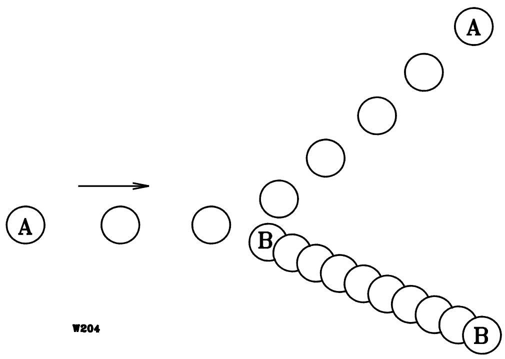
Questions



5. The figure shows successive positions of a ball at equal time intervals before and after receiving an impulse near point X. The vector **p** represents the momentum of the ball before the impulse. Construct the following vector diagrams.

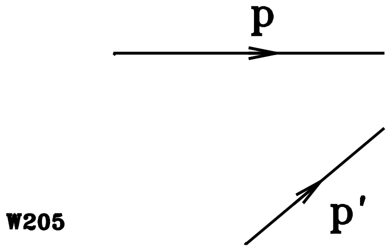


   (a) After making appropriate measurements draw a vector **p**λ to represent the momentum of the ball after collision.
   (b) Construct the vector which represents the change in momentum **Δp** of the ball.
   (c) Draw a vector to represent the impulse **I** exerted on the ball.



6. The figure shows the successive positions of two balls A and B before and after a collision in which ball A strikes a stationary ball B.

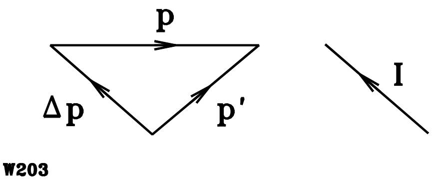
(a) The vector **p** represents the momentum of the ball before the collision and the vector **p′** to represents the momentum of the ball after collision. Draw a vector representing the momentum **P** of ball B after the collision.



(b) Is the length of this vector consistent with the close spacing of the images of ball B? Explain.

Answers

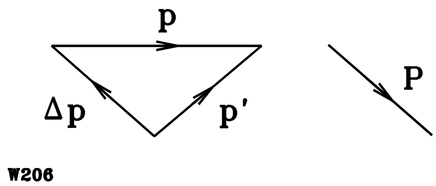
5. (a) Measurement of the positions of the ball after impact show that the speed of the ball after the impulse is approximately two-thirds of its initial speed. The momentum vector **p′** is therefore two-thirds of the length of **p** and its direction is in the direction of the final path of the ball.



(b) Subtraction of **p** from **p′** yields the vector **Δp**.

(c) Vector **I** is of the same magnitude and direction as vector **Δp**. The change in momentum is equal to the impulse.

6.



(a) Since momentum is conserved in a collision, the change in momentum of ball B is equal and opposite to the change in momentum of ball A i.e. **P** = -(**p′** - **p**). This is shown in the figure, which is very similar to that of the previous question. The **I** vector there represents the impulse on ball A and the impulse on ball B (its change in momentum) is equal and opposite to this.

(b) Vector **P** is quite long while the spacing between successive positions of ball B is quite small, indicating a small velocity. These two facts are quite consistent. ball B is much heavier than ball A. Although its velocity is small its momentum mv is large.

You may have made the error of measuring the spacing of the successive positions of ball B and assuming that B and A were of the same mass.