Impulse

In order to change the momentum of an object, either its mass, its velocity, or both must change. If the mass remains unchanged, which is most often the case, then the velocity changes and acceleration occurs. We know that acceleration is caused by a force.

Two factors influence the amount by which an object's momentum changes.

1. The size of the force.
   - the greater the force acting on the object, the greater its change in momentum

2. How long the force acts.
   - a force sustained for a long time produces a greater change in momentum than the same force applied briefly

The amount by which an object's momentum changes can be determined using Newton's second law.

$$\begin{aligned} F &= ma \\ &= m\left(\frac{\Delta v}{\Delta t}\right) \end{aligned}$$

$$\boxed{F\Delta t = m\Delta v}$$

The quantity $F\Delta t$ is called **impulse**. In general, the greater the impulse exerted on an object, the greater will be its change in momentum.

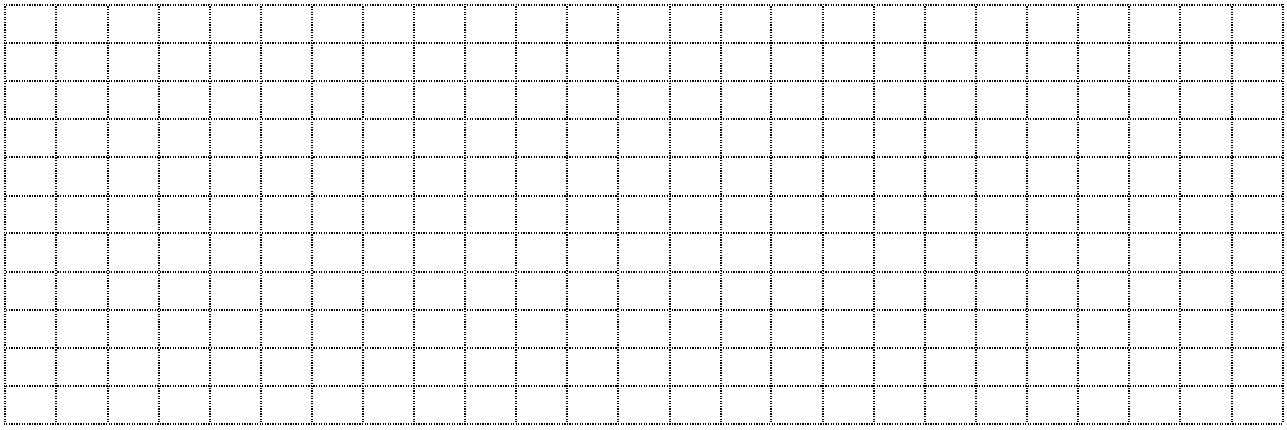
The quantity $m\Delta v$ is simply the change in the object's momentum, expressed mathematically. Thus, the formula above could be interpreted as

impulse = change in momentum

Note: The units of impulse are $N \cdot s$.

Impulse – A Graphical Interpretation

Consider the following graph of the force acting on an object over a given time interval.



From this graph we can see that the impulse acting on an object is given by the area bounded by the force-time graph.

impulse = area bounded by force-time graph

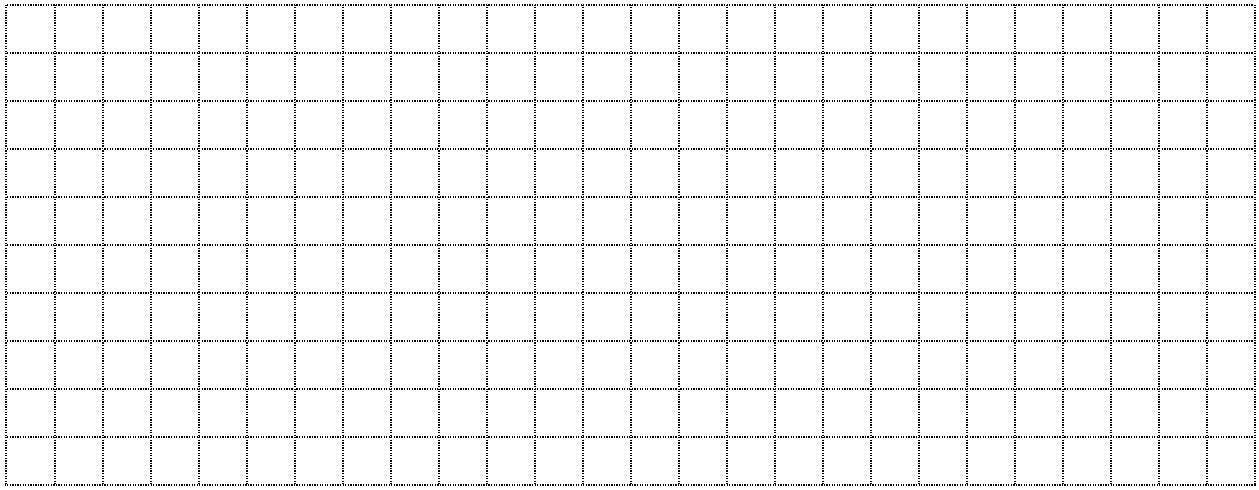
In other words, the change in an object's momentum can be found using a graph of force vs. time.

change in momentum = area bounded by force-time graph

Example 1
What is the impulse given to a golf ball by a club if they are in contact for $0.0050\ s$, during which the club exerts an average force of $500\ N$ on the ball?

Example 2
A baseball has a mass of $0.14\ kg$ and an initial velocity of $30\ m/s$. It rebounds from a bat with a velocity of $40\ m/s$ in the opposite direction. If the bat is in contact with the ball for $0.0020\ s$, determine the average force exerted on the ball by the bat.

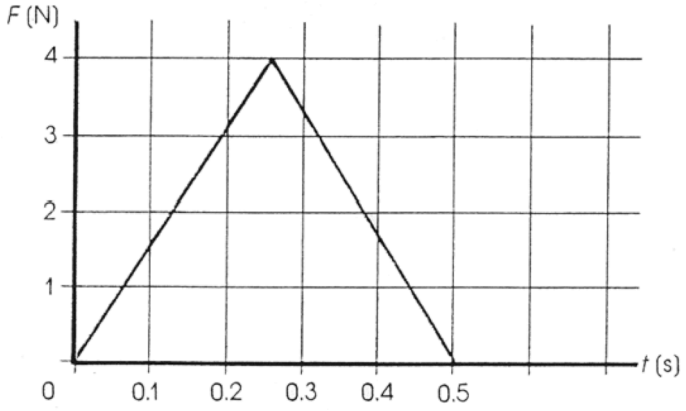
Example 3
The graph below approximates the force applied to a tennis ball by a racket during the time they are in contact.



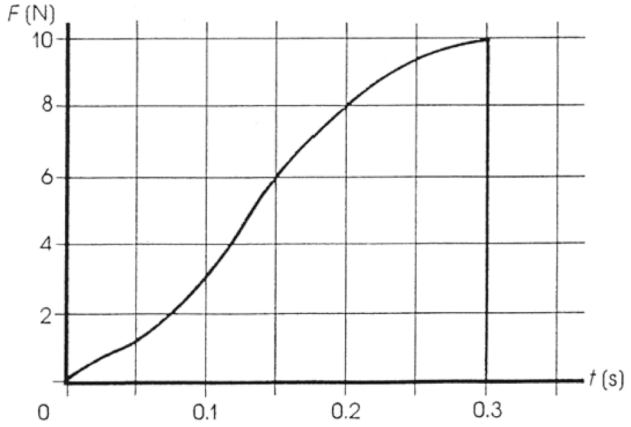
What impulse does the ball receive from the racket?

Momentum Worksheet #2

1. What impulse is exerted in each of the following cases?
   a) a force of $25\ N\ [E]$ on a dynamics cart for $3.2\ s$ ($80\ N \cdot s\ \left[E\right]$)
   b) a hockey stick exerting a force of $120\ N$ on a puck during the $0.05\ s$ they are in contact ($6\ N \cdot s\ \left[forward\right]$)
   c) the Earth pulling down on a $12\ kg$ rock during the $3.0\ s$ it takes to fall from a cliff ($3.5 \times 10^2\ N \cdot s\ \left[down\right]$)
   d) a billiard ball bouncing off a cushion, if the force-time graph of the collision appears as below ($1\ N \cdot s\ \left[opposite\ ball's\ original\ motion\right]$)



   e) a collision between a toy car and a brick wall, if the force-time graph of the collision appears as below ($1.5\ N \cdot s\ \left[opposite\ ball's\ original\ motion\right]$)



2. A billiard ball of mass $200\,g$ rolls toward the right-hand cushion of a billiard table at $2.0\,m/s$ and rebounds straight back at $2.0\,m/s$
   a) What is its change in momentum as a result of hitting the cushion? ($0.80\,kg \cdot m/s\ [left]$)
   b) What impulse is given to the ball by the cushion? ($0.80\,N \cdot s\ [left]$)

3. A hockey puck of mass $0.20\,kg$ is sliding along a smooth, flat section of ice at $18\,m/s$ when it encounters some snow. After $2.5\,s$ of sliding through the snow, it returns to smooth ice, continuing at a speed of $10\,m/s$.
   a) What is the change in momentum of the puck? ($1.6\,kg \cdot m/s\ [backward]$)
   b) What impulse does the snow exert on the puck? ($1.6\,N \cdot s\ [backward]$)
   c) What average frictional force does the snow exert on the puck? ($0.64\,N\ [backward]$)

4. A frictionless disc of mass $0.50\,kg$ is moving in a straight line across an air table at a speed of $2.4\,m/s$ when it bumps into an elastic band stretched between two fixed posts. If the elastic band exerts an average opposing force of $1.4\,N$ on the disc for $1.5\,s$, what will be the final velocity of the disc? ($1.8\,m/s\ [backward]$)

5. A $2.0\,kg$ skateboard is rolling across a smooth, flat floor when a small girl kicks it, causing it to speed up to $4.5\,m/s$ in $0.50\,s$ without changing direction. If the average force exerted by the girl on the skateboard in its direction of motion was $6.0\,N$, with what initial velocity was it moving? ($3.0\,m/s\ [forward]$)

6. A croquet mallet delivers an impulse of $8.83\,N \cdot s$ to a $0.44\,kg$ croquet ball initially at rest. What is the speed of the ball immediately after being struck? ($20.1\,m/s$)

7. The engine of a model rocket is rated with a total impulse of $5.00\,N \cdot s$ and a thrust duration of $1.20\,s$. What is the average force exerted by the engine? ($4.17\,N$)

8. A $0.145\,kg$ baseball traveling $35.2\,m/s$ is stopped in $0.163\,s$ by a catcher's mitt.
   a) What is the average acceleration of the ball? ($-215.95\,m/s^2$)
   b) What is the average force on the catcher's mitt? ($31.3\,N$)

9. A $68\,kg$ soccer player kicks a stationary $0.425\,kg$ ball giving it a speed of $13.7\,m/s$. The player's foot is in contact with the ball for $0.097\,s$.
   a) What is the average force on the ball? ($60\,N$)
   b) What is the average force on the player's foot? ($60\,N$ in the opposite direction)

10. A $0.14\,kg$ baseball with an initial speed of $28\,m/s$ rebounds with a speed of $34\,m/s$ after being struck with a bat. If the duration of contact between ball and bat was $2.1\,ms$, what was the average force between ball and bat? ($4.1 \times 10^3\,N$)