

Momentum: Unit 1 Notes

Level 1: Introduction to Momentum

The Definition

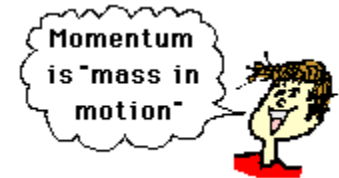
Momentum is a word we sometime use in everyday language. When we say someone has a lot of momentum, it means they are on a roll, difficult to stop, really moving forward. In physics, **momentum** means “mass in motion”. The more mass an object has, the more momentum it has. The more velocity an object has, the more momentum it has.

more mass → more momentum

less mass → less momentum

more velocity → more momentum

less velocity → less momentum



The Equation

The equation for momentum is:

$$\mathbf{Momentum} = \mathbf{mass} \times \mathbf{velocity}$$

In physics, we use the symbol p for momentum. Why? No idea- it has something to do with Latin, I think. Doesn't matter. I know it is annoying. Memorize it.

$p \rightarrow$ momentum

So using p for momentum, we can say:

$$\mathbf{p} = \mathbf{mv}$$

Units

The units for momentum are $kg \cdot m/s$. This makes a lot of sense, because $p=mv$ and mass is measured in kg, velocity is measured in meters per second (m/s), so we would expect momentum (mass x velocity) to be $kg \cdot m/s$.

Momentum as a Vector

Momentum is a vector. **Vector** is a fancy word for saying the direction matters. We have already dealt with tons of vectors this year- displacement, velocity, force... We show direction in lots of ways. Sometimes we state the geographic direction- north, south, east, west. Sometimes we use more local definitions- up, down, left, right. Sometimes we simply decide one direction is positive and another is negative. We have worked with all these before. For now, **you need to remember that if you state the momentum, you need to state the direction.**

How will you know the direction? Generally, that's easy. It will always be the same direction as the velocity of the object. If this sounds confusing, don't worry, it won't be. Take a look at a couple of the practice problems below and you'll see what I mean.

Practice Problem

Let's make sure you are comfortable calculating with the basic equation before we move on. Try the practice problems below. I put the solutions on the right for you. Don't just look at them and move on. *You are likely to get confused later on when you are asked to solve more complicated problems.*

Determine the momentum of a ...

- a. 60-kg halfback moving eastward at 9 m/s.
- b. 1000-kg car moving northward at 20 m/s.
- c. 40-kg freshman moving southward at 2 m/s.

A. $p = m \cdot v = 60 \text{ kg} \cdot 9 \text{ m/s}$

$p = 540 \text{ kg} \cdot \text{m/s, east}$

B. $p = m \cdot v = 1000 \text{ kg} \cdot 20 \text{ m/s}$

$p = 20\,000 \text{ kg} \cdot \text{m/s, north}$

C. $p = m \cdot v = 40 \text{ kg} \cdot 2 \text{ m/s}$

$p = 80 \text{ kg} \cdot \text{m/s, south}$

Level 2: Changing an Object's Momentum

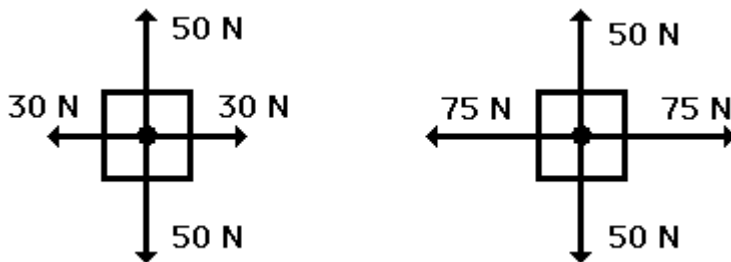
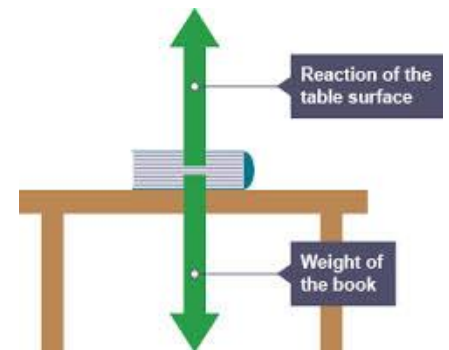
Now that you know how to calculate an object's momentum, let's talk about how we would change it. The momentum of an object doesn't always stay the same. For example, a car would have more momentum when it is speeding along a highway than when it is inching toward a stoplight.

How can you tell if an object is experiencing a change in momentum? If it is slowing down or speeding up, it is experiencing a change in momentum.

Unbalanced Forces change an object's momentum. Your life has already shown you innumerable examples of this. In the example of a car slowing to a stop, the brakes are applying a force to the car, changing its momentum and slowing it to a stop.

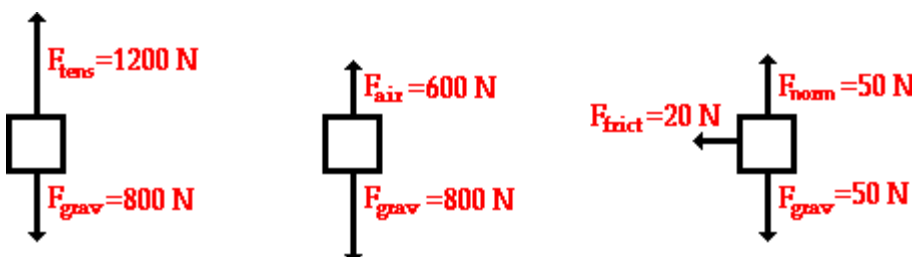
If you have an unbalanced force acting on an object, the object's momentum is changing.

We already learned about balanced and unbalanced forces. **Balanced forces** are forces that are canceled out by other forces. For example, the normal force and gravity are balanced forces (see the picture on the right). They have the same strength and are acting in opposite direction. The two forces are balanced and they cancel each other out. This means the object is not experiencing a change in momentum- it is not speeding up or slowing down. There are some more examples of balanced forces below.



In all the situations above (with balanced forces) the object is not experiencing a change in momentum. It is not speeding up or slowing down.

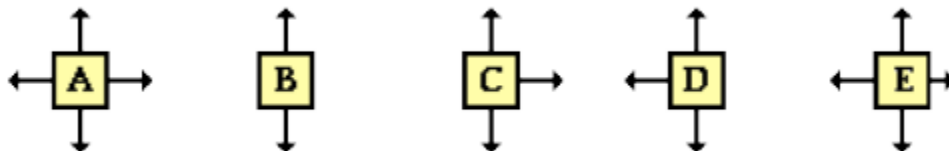
Unbalanced forces are forces that are not canceled out by a force acting in the opposite direction. Here are examples of several unbalanced forces. In the one on the far right, you can see there are two balanced forces and one unbalanced force.



Object that have unbalanced forces acting on them are experiencing a change in momentum. Let's make sure you get this before we move on.

Practice Problem

Circle the objects that will be experiencing a change in momentum



Solution

Did you circle C,D, and E? Good. I think you've got it.

Level 3: Impulse

The change in momentum is called the **impulse**. Any object that is changing its momentum is experiencing an impulse. **The impulse is caused by an unbalanced force.**

Impulse = change in momentum

Impulse = final momentum – initial momentum

Impulse = $p_f - p_i$

Sometimes, people like to show $p_f - p_i$ as Δp so we can also write this as:

Impulse = Δp

In other words, impulse is the change in momentum. They are the same thing. If you find the change in momentum, you have the impulse. If you have the impulse, you know the change in momentum.

Practice Problem

A ball (mass=0.5 kg) is rolling along the floor with a velocity of 2 m/s in the positive direction. A foot kicks it, speeding it up until its velocity is 3 m/s in the positive direction.

- What was the ball's initial momentum? (Answer: 1 kg m/s)
- What was the ball's final momentum? (Answer: 1.5 kg m/s)
- What was the impulse on the ball? (Answer: 1.5-1 = 0.5 kg m/s)

Calculating Impulse

We've talked about how to change momentum- by applying an unbalanced force. And we've said that the change in momentum is impulse. So how are the force and the impulse related?

Impulse = Force · time

Force is the unbalanced force acting on the object. **Time** is the amount of time the force is acting on the object. For example, you might have a bungee cord pull you up for 30 seconds. Or you could have bat acting on a ball for 0.01 second.

Let's put it all together.

change in momentum = impulse = force · time

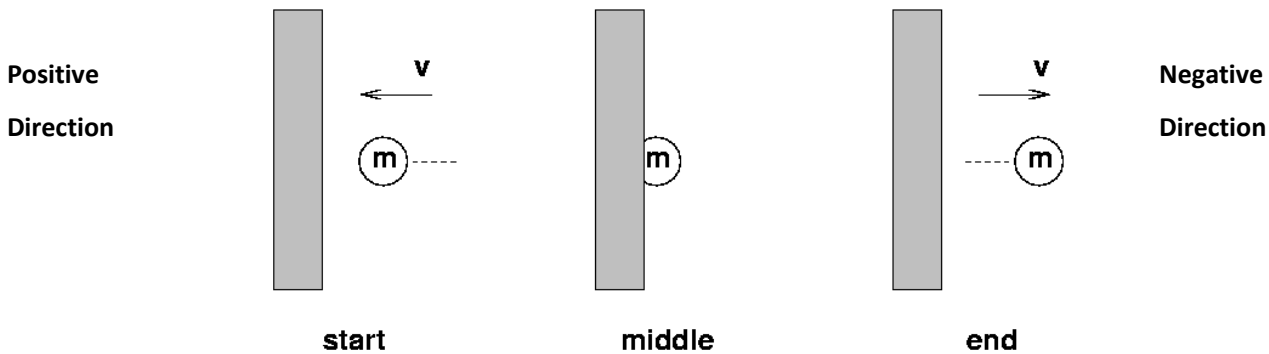
$p_f - p_i = impulse = Ft$

$p_f - p_i = Ft$

In other words, if you know how long a force is acting on an object, you can calculate how much its momentum changed.

Level 3: Bounce Problems

There is one type of momentum problem that weirds out most physics students when they first encounter them. They aren't actually hard- but they do force you to deal with the fact that momentum is a vector- that its direction matters. I call these **bounce problems**- they happen when we have an object change direction. For example, a ball hitting a wall.



In this problem, I decided that left was positive and right was negative. Why? Because *I do what I want*. You're allowed to do things like that in physics. That's how we roll. If I'd chosen the right side to be positive and the left to be negative, the problem would work out the same, as long as I stuck to that rule all the way through the problem. I'm going to walk you through one below. **Complete the calculations in the example below on a separate piece of paper. I will ask to see your work!**

The ball in the problem above has a mass of 2 kg. At first, it is traveling toward the wall with a velocity of 3 m/s. What is the momentum of the ball? Calculate that now. It's easy.

You should have said the momentum is +6 kg m/s (watch those units). Alright, now imagine the ball hits a wall, and afterward, it is still moving 3 m/s. Did its momentum change? Yes. Look carefully. **The ball now has a velocity in the negative direction.** So technically, its velocity is -3m/s. Because it is going in the negative direction now. Calculate its new momentum.

Did you say -6 kg m/s? Then you, sir, are a genius. Good for you! Now the last part. Calculate the impulse on the ball- the change in the ball's momentum. Your gut might tell you it will be zero, but your gut is dead wrong. Try this first, then look at what I did below. Do it this way or these problems will make no sense to you.

Calculate the ball's impulse:

Solution:

$$\text{Impulse} = p_f - p_i$$

$$\text{Impulse} = (-6) - (6)$$

$$\text{Impulse} = -6 + -6$$

$$\text{Impulse} = -12 \text{ kg m/s}$$

Let's take this one step further. Let's say that the ball was hitting the wall and changing direction for 0.2 seconds. What was the force on the ball? You try it first, then check the solution.

Solution

$$\text{Impulse} = -12 \text{ kg m/s}$$

$$\text{Impulse} = \text{Force} \cdot \text{time}$$

$$-12 = F (0.2)$$

$$F = -60 \text{ N}$$

Why the negative? Look back up at the picture. **The wall pushed the ball in the negative direction.**

Level 4: Real Life Problems

Momentum is one of those areas of physics where once you learn it, you can't un-see it. You will notice it everywhere and it has a lot of real world applications. In this sections, we are going to apply what we've learned so far to several real world situations. Specifically, we are going to look at two key ideas:

- How collision time effects the force acting on an object.
- How rebounding effects the force on an object (this is an application of bounce problems).

How Time Effects Force

Let's say we wanted we had a child sitting in a wagon at rest (their combined mass is 60 kg) We want the kid to have fun, so we are going to push the wagon and accelerate it to a velocity of 6 m/s. Weeee!

What is the initial momentum of the kid and wagon? _____

What is the final momentum of the kid and wagon? _____

If you don't know how to calculate these go back and look at your Level 1 Notes and Practice Problems.

There are two ways we could speed this kid/wagon up. We could do it slowly. We could speed the kid up over the course of 100 seconds. How much force would this take?

If you struggled to calculate this, go back and look at your Level 3 notes and practice problems.

The other way you could speed the kid up is to jerk the wagon forward really fast. Let's we speed the kid up in only 0.5 seconds. Now much force was acting on the kid? The change in momentum is the same remember- we still have the same initial and final velocities.

Wow! That is a *huge* difference in force. Now the kid would have whiplash. There would be tears and lawsuits.

If a change in momentum takes place over a long period of time, the force is small.

If a change in momentum occurs quickly, the force is huge.

Think about punching someone in the face. When you punch someone, you are essentially accelerating their face- making it speed up. If you do this very quickly, you will apply more force. If you do this slowly, they will hardly feel it. This is why Mohammed Ali said "Float like a butterfly, sting like a bee." The faster you hit, the more hit hurts.

If you are slower at hitting, you will need to apply more force in order to have the same impact.

$$F \Delta t = \text{change in momentum}$$



$$F \Delta t = \text{change in momentum}$$



Let's say I'm deciding to punch a wall or a pillow. I'm in a terrible mood, so either way my fist is going to be moving pretty quickly toward the object. In the end, my hand will come to a stop. So for both the pillow and the wall, the change in the momentum of my hand will be the same.

Pillow	Wall
change in momentum = Δp	change in momentum = Δp

Which one is safer for me to hit? The pillow, of course. Why? Because the pillow will take longer to slow down my hand than the wall, which will stop my hand in a fraction of a second. Because time is much much longer for the pillow, we can say:

Pillow	Wall
change in momentum = Δp	change in momentum = Δp
TIME	time
Force	FORCE