This packet introduces you to momentum, the conservation of momentum, and problems involving collisions and explosions.

Part A: The Momentum Formula
Part B: Straightforward Collision Problems
Part C: More complex collision problems.
Part D: Momentum problems with a larger formula

Part A: The Momentum Formula

$$p = mv$$

Symbol	Quantity	SI unit
p	Momentum	kg m/s
m	Mass	kg
v	velocity	m/s

Why do you think momentum *p* and not *m*?

A.1. I have a mass of 15 kg and a velocity of 3 m/s. What is my momentum?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

A.2. I have a mass of 30 kg and a velocity of 20 m/s. What is my momentum?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

A.3. I have a momentum of 120 kg m/s and a velocity of 20 m/s. What is my mass?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

A.4. A moving car as a mass of 2,000 kg and a momentum of 10,000 kg m/s. What is its velocity?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

A.5. A rolling ball has a mass of 0.5 kg and a momentum of 1 kg m/s. What is its velocity?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

A.6. A truck on the highway has a mass of 5,000 kg and a velocity of 20 m/s. What is its momentum?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

A.7. A turtle is rollin' on a skateboard with a velocity of 4.0 m/s and a momentum of 13.2 kg m/s. What is its mass?

Looking For	Formula
Already Know	
Answer in a complete sentence with unit	

Part B: Straightforward Collision Problems

Rules:
Total momentum = Momentum A + Momentum B

The Conservation of Momentum
The total momentum of the system is the same before the collision and after the collision!

B1.
Before the collision…
Car A has a mass of 400 kg and is moving right with a speed of 20 m/s before the collision.
Car B has a mass of 300 kg and is stationary before the collision.

After the collision….
Car A is stationary.
How fast is car B moving?

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

B.2.
Before the collision….
Car A has a mass of 200 kg and is stationary.
Car B has a mass of 400 kg and is moving right with a speed of 10 m/s.

After the collision……
Car B is stationary.
How fast is car A moving?

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

Velocity is a *vector*!

If something is moving RIGHT, its velocity is *positive*.

If something is moving LEFT, its velocity is *negative*.

B.3.
Before the collision…
Car A has a mass of 200 kg and is moving 5 m/s to the right.
Car B has a mass of 150 kg and is moving 7 m/s to the left.

After the collision…
Car A is stationary.
What is the *direction* and *magnitude* of the velocity of car B?

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

B.4 Before the collision…
Car A has a mass of 220 kg and is moving 6.0 m/s to the right.
Car B has a mass of 180 kg and is moving 4.0 m/s to the left.
After the collision…
Car A is moving 2.0 m/s to the left.
What is the *direction* and *magnitude* of the velocity of car B?

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

B.5 Perfectly inelastic collision…this means that after the collision the cars are stuck together.
Before the collision….
Car A has a mass of 330 kg and is moving 12 m/s to the right.
Car B has a mass of 220 kg and is moving 2 m/s to the right.
After the collision…
Cars A and B are stuck together.

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

What is the velocity of the two cars, stuck together?

B.6.
An explosion problem. In this problem, a cannon and cannonball both begin stationary. An explosion happens, the cannonball moves one was and the cannon moves back the other way. The cannon moving backward is called the *recoil*, and occurs whenever a cannon or gun is fired.

The POSITIVE direction is *forward*.
The NEGATIVE direction is *backward*.

Before the explosion….
The cannon has a mass of 1100 kilograms.
The cannonball has a mass of 8.4 kilograms.
Both are stationary (velocity = 0)

After the explosion….
The cannonball has a speed of 323 meters/second *forward*.
What is the *magnitude* and *direction* of the cannon? [this is called the *recoil* of the cannon.]

Draw the problem:

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Cannon	Cannonball		Cannon	Cannonball
Mass					
Velocity			Total momentum		
Momentum					

Part C: More complex collision problems.
The difference is that now, these are problems from a traditional physics book written out as paragraphs. Many come from Essential Physics, the physics book for this course or Glencoe physics, Mr. Kuncik's old physics book.

C.1. [chapter 11 #62 in Essential Physics]
A 2,000 kg car moving at 10 m/s collides head-on with a 2,500 kg car moving in the opposite direction at 15 m/s. The two cars are locked together after impact. [this is called an *inelastic collision*]. What is the speed of the cars after impact?

	BEFORE COLLSION			AFTER COLLSION
	Drawing			Drawing
	Car A	Car B		Car A and Car B
Mass				
Velocity			Total momentum	
Momentum				

C.2. [chapter 11 # 63 essential physics]
A stationary 165 kg football player is hit by a 178 kg player running at 8.00 m/s. They begin moving while stuck together. How faster are they going after impact?

	BEFORE COLLSION			AFTER COLLSION
	Drawing			Drawing
	Player A	Player B		Player A and Player B
Mass				
Velocity			Total momentum	
Momentum				

C.3. A 70.9 kg boy and a 43.2 kg girl, both wearing skates face each other *at rest* on a skating rink. The boy pushes the girl, sending her eastward with a speed of 4.64 m/s. Neglecting friction, determine the subsequent velocity of the boy.

Say eastward is POSITIVE and westward is NEGATIVE.
This problem is similar to the explosion problems above.

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass					
Velocity			Total momentum		
Momentum					
Final Answer in a complete sentence with unit with unit:					

C.4. Mr. H ignites the enthusiasm of the class with a home-made cannon demonstration. The 1.27 kg cannon is loaded with a .054 kg tennis ball and placed on the floor. Mr. H adds the fuel, waits for its vapors to fill the reaction chamber and then brings a match nearby. The explosion stuns the crowd and propels the ball forward. A photogate measurement determines that the cannon recoiled backwards with a speed of 7.8 m/s. Determine the speed of the ball.

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Cannon	Cannonball		Cannon	Cannonball
Mass					
Velocity			Total momentum		
Momentum					

Final Answer in a complete sentence with unit with unit:

C.5. An 82-kg male and a 48-kg female pair figure skating team are gliding across the ice at 7.4 m/s, preparing for a throw jump maneuver. They are gliding together. The male skater tosses the female skater forward with a speed of 8.6 m/s. Determine the speed of the male skater immediately after the throw.

	BEFORE COLLSION		AFTER COLLSION	
	Drawing		Drawing	
	Male and Female Skater		Male Skater	Female Skater
Mass				
Velocity		Total momentum		
Momentum				

Final Answer in a complete sentence with unit with unit:

C.6. [chapter 11 #64 essential physics, adapted]
In an elastic collision, a 1.0 kg ball moving at 1.0 m/s collides with a 2.0 kg ball moving at −2.0 m/s. The 2.0 kg ball is stationary after the collision. What is the speed of the 1.0 kg ball after the collision?

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Ball A	Ball B		Ball A	Ball B
Mass					
Velocity			Total momentum		
Momentum					

Part D: Momentum problems with a larger formula

Challenge: instead of using the tables to solve the problems, use the following mathematical formula:
1 means before the collision
2 means after the collision

$$m_a v_{a1} + m_b v_{b1} = m_a v_{a2} + m_b v_{b2}$$

Symbol	Quantity		Symbol	Quantity
m_a	Mass of object A		v_{a2}	Velocity of object A after collision
v_{a1}	Velocity of object A before collision		v_{b2}	Velocity of object B after collision
m_b	Mass of object B			
v_{b1}	Velocity of object B before collision			

D.1 [Essential physics Chapter 11 #61]
A 2.0 kg puck is moving east at 5.5 m/s. It catches up to and collides with a second identical puck moving due east at 3.0 m/s. The collision is perfectly inelastic. [they stick together]

This is the version of the equation used for perfectly inelastic collisions:

$$m_a v_{a1} + m_b v_{b1} = (m_a + m_b) v_2$$

v_2 is the speed of the two pucks after the collision. You are looking for v_2.

D.2. [Essential Physics Chapter 11 #60]
A 10,000 kg railroad car traveling north at 10 m/s collides with a 5,000 kg rail car also moving north but at an unknown speed. After the collision, the two cars lock together and move north at 8 m/s [called a perfectly inelastic collision]. How fast was the second car moving before the impact?

$$m_a v_{a1} + m_b v_{b1} = (m_a + m_b) v_2$$

D.3 [Essential Physics, Chapter 11 #77]
Two spring-loaded ballistic carts, one of 200 g and the other 800 g, are released and the lighter cart is observed to move at +1 m/s afterward. What is the velocity of the other cart?

$$m_a v_{a1} + m_b v_{b1} = m_a v_{a2} + m_b v_{b2}$$

Part E: Deriving the Formula

Derive an equation for general collision problems:

Car A has a mass of m_A and is moving before the collision with a velocity v_{A1}.

Car B has a mass of m_B and is moving before the collision with a velocity of v_{B1}.

The two cars collide. Their masses do not change.

After the collision, car A is moving with a velocity of v_{A2}
and car B is moving with a velocity of v_{B2}.

Using the table below and the *conservation of momentum*, create an algebraic equation to represent this collision:
[There is a lager space to write "total momentum" where you can include the formula."

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Car A	Car B		Car A	Car B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

MATH: Collisions and explosions Name _____

Derive an Equation for perfectly inelastic collision problems:

Car A has a mass of m_A and is moving before the collision with a velocity v_{A1}.

Car B has a mass of m_B and is moving before the collision with a velocity of v_{B1}.

The two cars collide and stick together (a perfectly inelastic collision). Their masses do not change.
After the collision, their combined velocity is v_2.

Using the table below and the *conservation of momentum*, create an algebraic equation to represent this perfectly inelastic collision:
[There is a lager space to write "total momentum" where you can include the formula."

	BEFORE COLLSION			AFTER COLLSION
	Drawing			Drawing
	Car A	Car B		Car A and Car B
Mass (kg)				
Velocity (m/s)			Total momentum	
Momentum (kg m/s)				

Derive an equation for explosions [or push-off problems]

Cannon A has a mass of m_A and is not moving.
Cannonball B has a mass of m_B and is not moving.

They explode! Their masses do not change during the explosions.
After the explosion,
cannonball B has a velocity of v_B and the cannon has a recoil velocity of v_A.

Using the table, derive a conservation of momentum equation that relates the quantities m_A, m_B, v_A, and v_B.

	BEFORE COLLSION			AFTER COLLSION	
	Drawing			Drawing	
	Cannon A	Cannonball B		Cannon A	Cannonball B
Mass (kg)					
Velocity (m/s)			Total momentum		
Momentum (kg m/s)					

Answers:

A1. 45 kg m/s
A2. 600 kg m/s
A3. 6 kg
A4. 5 m/s
A5. 2 m/s
A6. 100,000 kg m/s
A.7 3.3 kg

B.1

	BEFORE COLLSION			AFTER COLLISION	
	Car A	Car B		Car A	Car B
Mass	400	300		400	300
Velocity	20	0	TOTAL MOMENTUM	0	26.7
Momentum	8000	0	8000	0	8000

Car B was moving at 26.7 m/s.

B.2.

	BEFORE COLLSION			AFTER COLLISION	
	Car A	Car B		Car A	Car B
Mass	200	400		200	400
Velocity	0	10	TOTAL MOMENTUM	20	0
Momentum	0	4000	4000	4000	0

Car A is moving at 20 m/s.

B.3.

	BEFORE COLLSION			AFTER COLLISION	
	Car A	Car B		Car A	Car B
Mass	200	150		200	150
Velocity	5	-7	TOTAL MOMENTUM	0	-0.33
Momentum	1000	-1050	- 50	0	-50

Car B has a velocity of 0.3 m/s to the left.

B.4

	BEFORE COLLSION			AFTER COLLSION	
	Car A	Car B		Car A	Car B
Mass	220	180		220	180
Velocity	6	- 4	Total momentum	2	0.89
Momentum	1320	- 720	600	440	160

B.5.

	BEFORE COLLSION			AFTER COLLISION
	Car A	Car B		Car A and Car B
Mass	330	220		550
Velocity	12	2	TOTAL MOMENTUM	8
Momentum	3960	440	4400	4400

They are moving together at a speed of 8 m/s.

B.6

	BEFORE COLLSION			AFTER COLLSION	
	Cannon	Cannonball		Cannon	Cannonball
Mass	1100	8.4		1100	8.4
Velocity	0	0	Total momentum	- 2.5	323
Momentum	0	0	0	-2713	2713

The cannon moves at a speed of - 2.5 m/s backwards.

C.1.

	BEFORE COLLSION			AFTER COLLSION	
	Car A	Car B		Car A	Car B
Mass	2,000	2,500		4,500	
Velocity	10	-15	Total momentum	- 3.9	
Momentum	20,000	-37,500	-17,500	-17,500	

The speed is 3.9 m/s.

C.2.

	BEFORE COLLSION			AFTER COLLSION
	Player A	Player B		Player A and Player B
Mass	165	178		343
Velocity	0	8.00	Total momentum	4.15
Momentum	0	1424	1424	1424

They move at 4.15 m/s.

C.3 2.83 m/s Westward

C.4 183 m/s

C.5 6.7 m/s (CHECK!!!)

C.6 3.0 m/s

D.1. 4.25 m/s

D.2. 4 m/s

D.3. -0.25 m/s