MOMENTUM DAY 1: IMPULSE & F-T GRAPHS

UNIT PREVIEW

In the Energy unit, we tracked *how much* motion changed. Now we ask: **what causes motion to change?** The answer is **impulse** — force applied over time — which leads to **momentum**, conserved in any collision, explosion, or interaction where no net external force acts on the system.

Over the next nine days, we'll build from impulse to conservation laws that explain car crashes, rocket launches, and why you bend your knees when you land.

□ Warm-Up: The Egg Drop (3 min)

Imagine dropping an egg onto two surfaces from the same height:

A. Concrete floor **B.** Thick foam pad

1. Which surface breaks the egg? ___

2. The egg's velocity change (Δv) is the same for both. What's different? ________________________

3. Prediction: Which has a larger *force* on the egg? ___

MOMENTUM: THE "QUANTITY OF MOTION"

MOMENTUM

$$\vec{p} = m\vec{v}$$

m = mass (kg)
$\vec{v}$ = velocity (m/s)
$\vec{p}$ = momentum (kg·m/s)
Momentum is a vector!

Why momentum? A 2000 kg car at 10 m/s and a 200 kg motorcycle at 100 m/s have the same momentum (20,000 kg·m/s). They're equally hard to stop—same force × time needed.

QUICK **Calculate Momentum**

a) A 0.145 kg baseball at 40 m/s:

b) A 1200 kg car at 25 m/s:

IMPULSE: FORCE OVER TIME

IMPULSE-MOMENTUM THEOREM

$$\vec{J} = \vec{F}_{\text{avg}} \cdot \Delta t = \Delta\vec{p} = m\Delta\vec{v}$$

Impulse (J) is force integrated over time. It equals the change in momentum. Units: N·s = kg·m/s

CALCULUS CORNER — STRIPS OF MOMENTUM

One strip under an F-t curve: (N)(s) = kg·m/s — a small parcel of momentum change. Same move as v-t strips (meters) and Unit 3's F-x strips (joules): the axes name what accumulates. Tomorrow the strips shrink into the impulse integral, $J = \int F(t)\,dt$.

REVISITING THE EGG DROP

WE DO **Same Impulse, Different Force**

An egg (m = 0.060 kg) falls and hits the ground at 5.0 m/s, coming to rest.

Find the impulse (change in momentum):

Hint: $J = \Delta p = m(v_f - v_i)$

Now find F_{avg} for each surface:

Surface	Δt	$F_{\text{avg}} = J/\Delta t$
Concrete	0.001 s	
Foam	0.10 s	

Why does the egg survive on foam? ______________________________

The Big Idea: Same Δp, longer Δt → smaller F. This is why we have airbags, crumple zones, and bend our knees when landing.

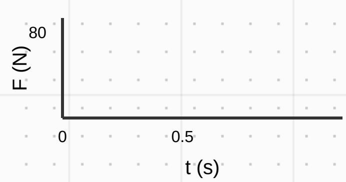
READING FORCE-TIME GRAPHS

Key insight: Impulse = **area under the F-t curve**. Just like work was area under F-x!

WE DO **F-t Graph: Rectangle**

A constant 80 N force acts on a cart for 0.50 s.

Sketch the F-t graph:



Find the impulse (area):

Shape: rectangle → Area = base × height

YOU DO **F-t Graph: Triangle**

A force starts at 120 N and decreases linearly to 0 over 0.20 s.

Sketch the F-t graph:

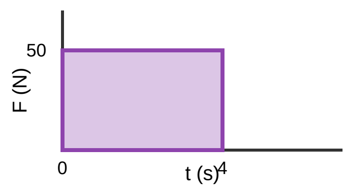
Find the impulse:

Shape: triangle → Area = ½ × base × height

CONNECTING IMPULSE TO VELOCITY CHANGE

WE DO **From F-t Graph to Final Velocity**

A 2.0 kg cart, initially at rest, experiences the force shown. Find its final velocity.



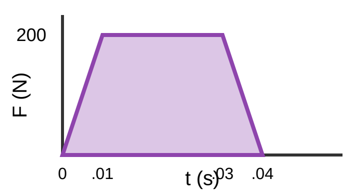
Step 1: Find impulse J (area):

Step 2: Use $J = m\Delta v$ to find Δv:

Step 3: Find v_f (given $v_i = 0$):

YOU DO **Trapezoid F-t Graph**

A 0.50 kg hockey puck, moving at 8.0 m/s, is hit by a stick. The force is shown below. Find the puck's final velocity.



Hint: Trapezoid area = ½(b_1 + b_2) × h

Show your work:

v_f = __________ m/s

Pattern: F-t graph → Area = J → $J = m\Delta v$ → solve for unknown velocity or mass.

HOMEWORK

1 **Conceptual**

A tennis ball and a lump of clay, both with the same mass and speed, hit a wall.

The tennis ball bounces back; the clay sticks. Which experiences the greater impulse? Explain.

2 Calculation: Stopping a Car

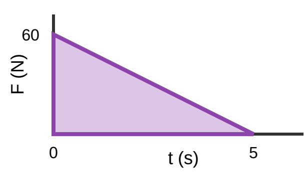
A 1500 kg car traveling at 20 m/s brakes to a stop.

a. What impulse is delivered to the car?

b. If the braking takes 4.0 s, what is the average braking force?

3 F-t Graph Analysis

A 3.0 kg object at rest is pushed with the force shown. Find its final speed.



4 Real-World Application

A baseball (0.145 kg) approaches a bat at 35 m/s and leaves at 45 m/s in the opposite direction. Contact time is 0.0012 s.

a. What is the impulse delivered to the ball? (Careful with signs!)

b. What is the average force on the ball?

c. How many times the ball's weight is this force?

5 Synthesis

Explain in 2-3 sentences why a karate expert can break a board with their hand but would injure themselves hitting a wall with the same speed.