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ROTATION DAY 3: TORQUE & LEVER ARM

WARM-UP (3 min): You need to loosen a stuck bolt. Rank these strategies by effectiveness (easiest to hardest):

- **A:** Push with 50 N using a long wrench, at the end, perpendicular to the wrench.
- **B:** Push with 100 N using a short wrench, at the end, perpendicular.
- **C:** Push with 100 N using a long wrench, but pushing at 30° to the wrench.
- **D:** Push with 100 N at the middle of the long wrench, perpendicular.

Prediction: ___ > ___ > ___ > ___ After we learn the equation, we'll check your ranking.

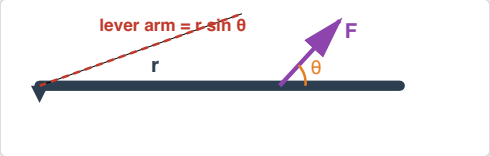
WHAT MAKES THINGS ROTATE?

TORQUE

$$\tau = rF\sin\theta$$

Where:

- r = distance from pivot to where force is applied (m)
- F = magnitude of force (N)
- θ = angle between the position vector and force vector
- τ = torque (N·m — NOT joules!)



Two equivalent ways to think about it:
(1) $\tau = (r\sin\theta)F = (\text{lever arm}) \times (\text{full force})$, or
(2) $\tau = r(F\sin\theta) = (\text{full distance}) \times (\text{perpendicular component of force})$.
Both give the same answer.

WE DO **Check the Warm-Up Rankings**

Now calculate τ for each bolt scenario:

Strategy	r (m)	F (N)	θ	$\tau = rF\sin\theta$ (N·m)
A	0.30	50	90°	
B	0.15	100	90°	
C	0.30	100	30°	
D	0.15	100	90°	

Final ranking: ___ > ___ > ___ > ___ Did your prediction match?

CALCULUS CORNER — TORQUE IS A CROSS PRODUCT (READ-ONLY)

τ = rF sinθ is the magnitude of a vector operation: **τ = r × F**, the cross product of the position vector (axis to the point where the force lands) with the force. ‖r × F‖ = rF sinθ — the sinθ is built in, and the right-hand rule assigns the sign your CCW/CW convention has been tracking by hand. Same physics, tighter packaging; you'll compute cross products directly later in the course.

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SIGN CONVENTION FOR TORQUE

POSITIVE AND NEGATIVE TORQUE

- **CCW = positive τ** (like standard math angles)
- **CW = negative τ**

Common mistake: Students assign the sign based on the direction of the force (up = positive). Wrong! The sign depends on which WAY the force would make the object rotate around the pivot.

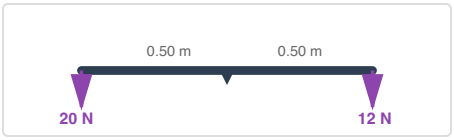
Physics in the Wild: The Cheater Bar

When a mechanic can't break a bolt loose, they slide a long pipe over the wrench handle — called a "cheater bar." It doubles or triples r while F stays the same, so torque skyrockets. Some cheater bars are over a meter long. Medieval castle doors had long handles for exactly the same reason: more torque from a weaker push.

Quick math: If a mechanic applies 200 N with a 0.30 m wrench and can't break a bolt free, what happens when they add a 0.60 m pipe? How much torque now?

WE DO Beam with Two Forces

A 1.0 m beam is pivoted at its center. A 20 N force pushes DOWN at the left end; a 12 N force pushes DOWN at the right end.



(a) Torque from left force (with sign):

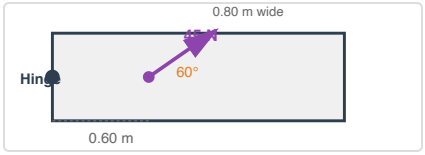
(b) Torque from right force (with sign):

(c) Net torque:

(d) Which way will the beam rotate?

YOU DO Angled Force on a Door

A door is 0.80 m wide (hinged on left). You push with 45 N at a 60° angle to the door surface, at a point 0.60 m from the hinges.



(a) Draw the lever arm on the diagram above. (Use a dashed line.)

(b) Calculate the torque about the hinge.

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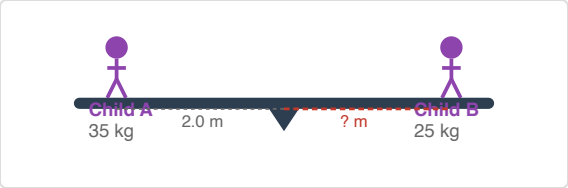
MULTIPLE TORQUES — NET TORQUE

WE DO Playground Seesaw

Two children sit on a seesaw (pivot in middle). Child A (mass 35 kg) sits 2.0 m from the pivot. Child B (mass 25 kg) sits on the other side.

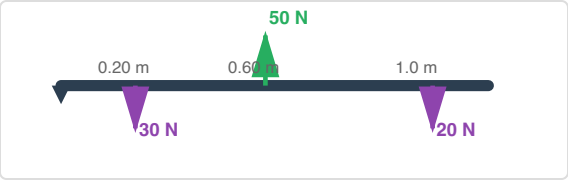


(a) Find the torque from Child A's weight about the pivot.

(b) How far from the pivot must Child B sit to balance the seesaw? (Set $\Sigma\tau = 0$.)

YOU DO Three Forces

A horizontal beam is pivoted at the left end. Forces: 30 N down at 0.20 m from pivot, 50 N up at 0.60 m from pivot, 20 N down at 1.0 m from pivot.



(a) Calculate each torque (with sign):

(b) Find net torque:

(c) Which way does the beam tend to rotate?

This is the foundation for statics (Day 4). If an object isn't rotating, the net torque MUST be zero. Tomorrow we use this to solve for unknown forces.

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EXIT TICKET & HOMEWORK

EXIT TICKET: A wrench is 0.25 m long. You apply 80 N at the end, perpendicular to the wrench.

(a) Find the torque:

(b) If you instead push at 45° to the wrench, what torque do you produce?

HOMEWORK

PROBLEM 1 Conceptual — Revolving Door

A force is applied to a revolving door. In which case is the torque greatest?

- **(a)** Pushing at the outer edge, perpendicular.
- **(b)** Pushing at the outer edge, at 45°.
- **(c)** Pushing halfway to center, perpendicular.
- **(d)** Pushing at the outer edge, parallel to the door.

Circle answer: ___ **Explain in one sentence:**

PROBLEM 2 Lever Arm Practice

A mechanic uses a 0.40 m wrench and applies 120 N at 75° to the wrench. Calculate the torque.

PROBLEM 3 Two-Force Balance

A uniform meter stick (mass 0.15 kg) is supported at the 40 cm mark. A 0.50 kg mass hangs at the 10 cm mark. Where should a 0.30 kg mass be placed to balance the stick? (Remember: the stick's weight acts at its center of mass — the 50 cm mark.)

PROBLEM 4 Looking Ahead

Tomorrow we tackle statics — objects that don't translate AND don't rotate. What TWO conditions must both be true? (Hint: one involves forces, one involves torques.)

Tomorrow: Static Equilibrium. Two conditions: $\Sigma F = 0$ AND $\Sigma \tau = 0$. It's Newton's Laws meets torque.