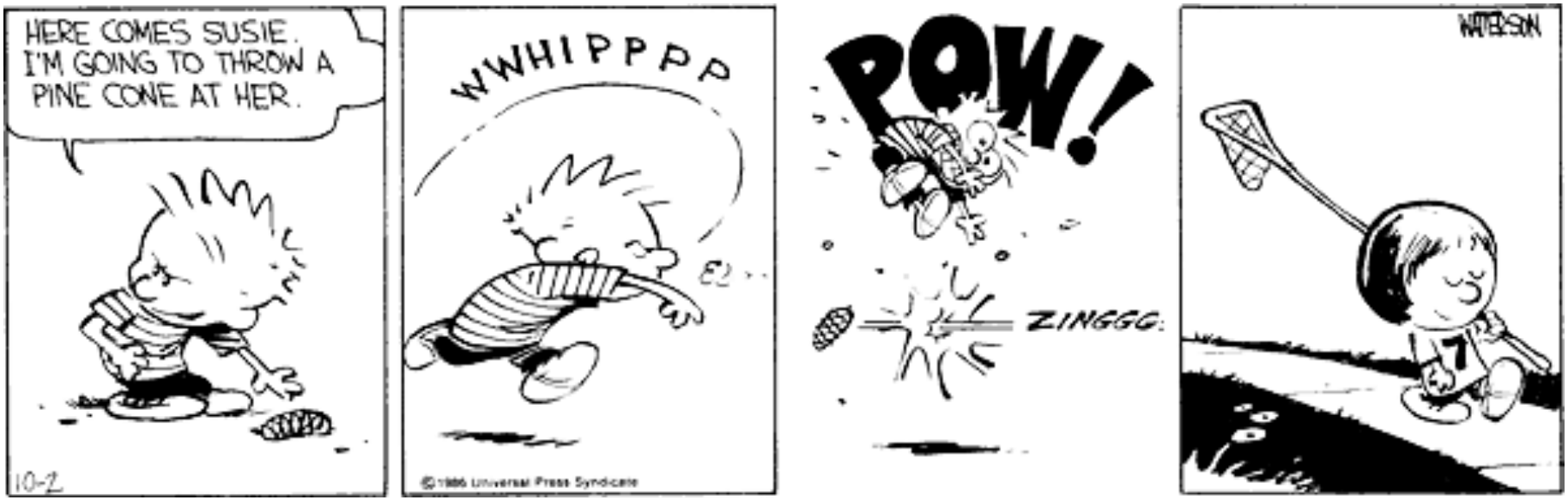
- **Theme Music: Depeche Mode**

  Get the Balance Right

- **Cartoon: Bill Watterson**

  Calvin & Hobbes

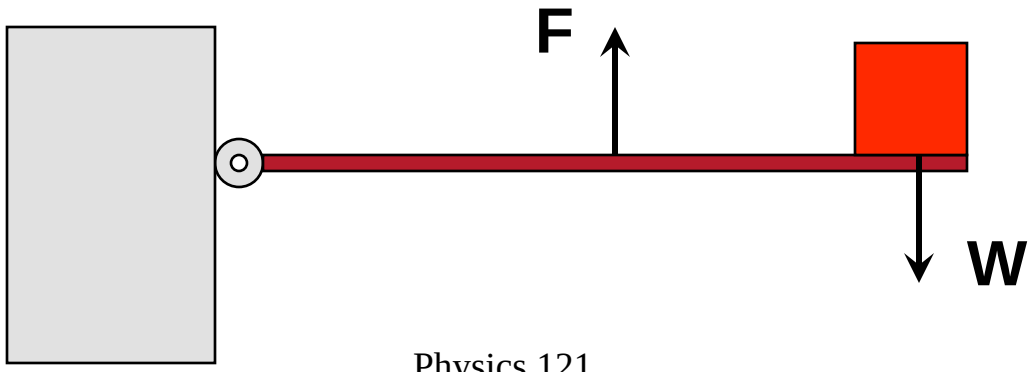


Outline

- Quiz 8: Circular motion
- Rotational Kinematics
  - angles
  - angular velocity
- Rotational Effect of Forces
  - Torque
  - examples

Rotational Effect of Forces: Relevant Factors

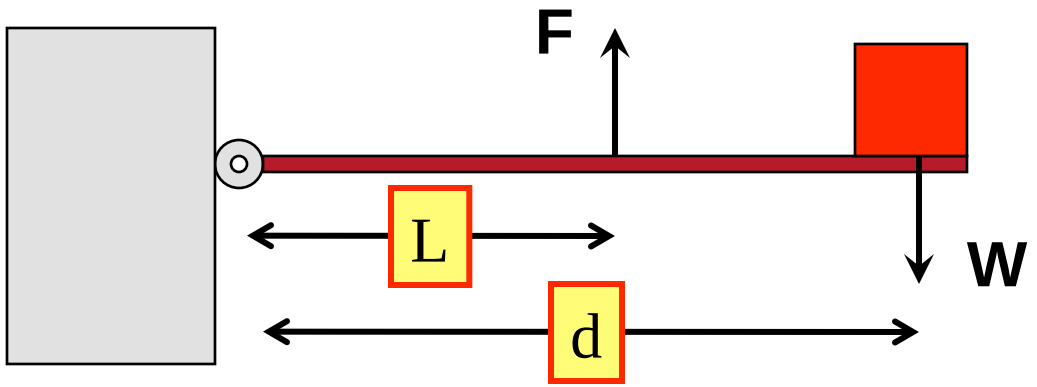
- How much force is needed to hold up a weight?
- The distance from the point of rotation clearly makes a difference with farther being more effective, nearer less.



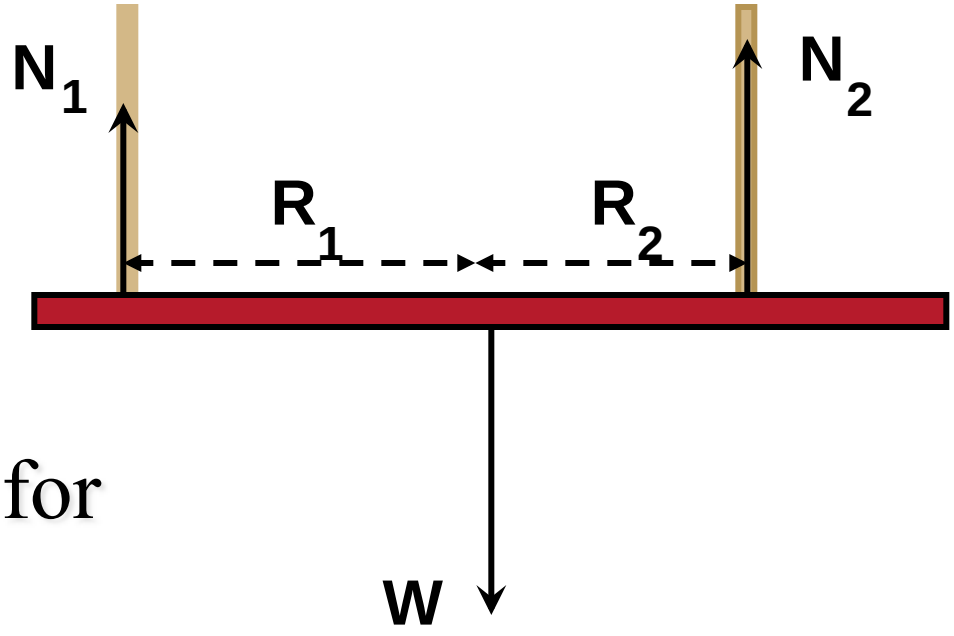
The balance rule

- Each force tries to turn the bar in a particular direction. When the forces and distances satisfy the balance rule, it stays balanced.

$$FL = Wd$$



Example: The Scaffold



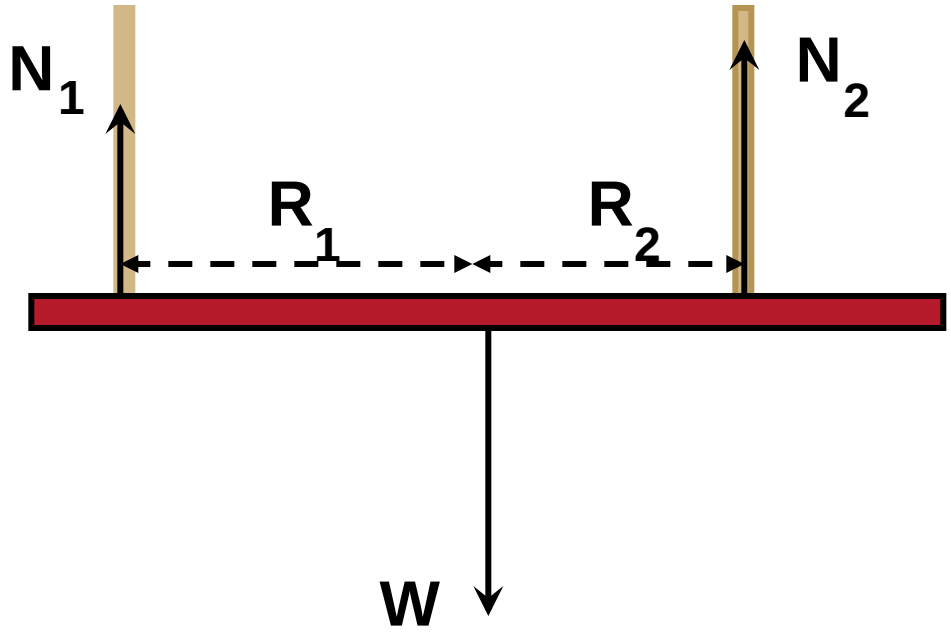
- Forces must balance for the CM not to move.
- Torques must balance for the object not to rotate about the CM.

$$\tau_{clockwise} = \tau_{counter-clockwise}$$

$$F_{up} = F_{down}$$

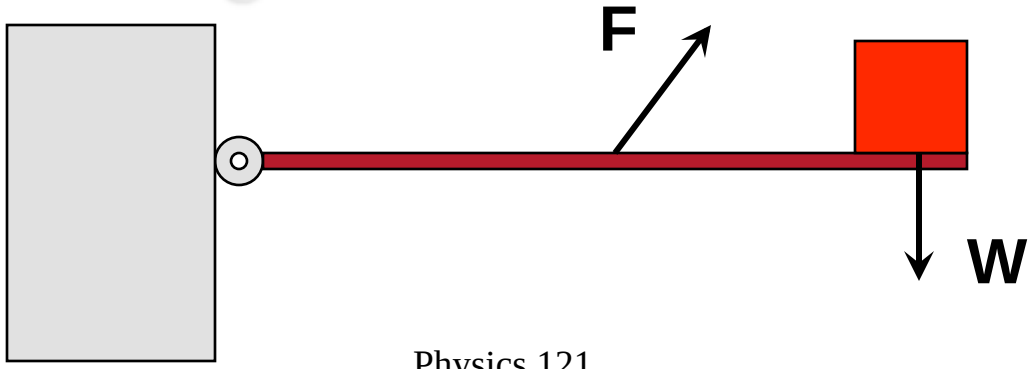
$$F_{left} = F_{right}$$

Does it matter is you choose a different reference point?



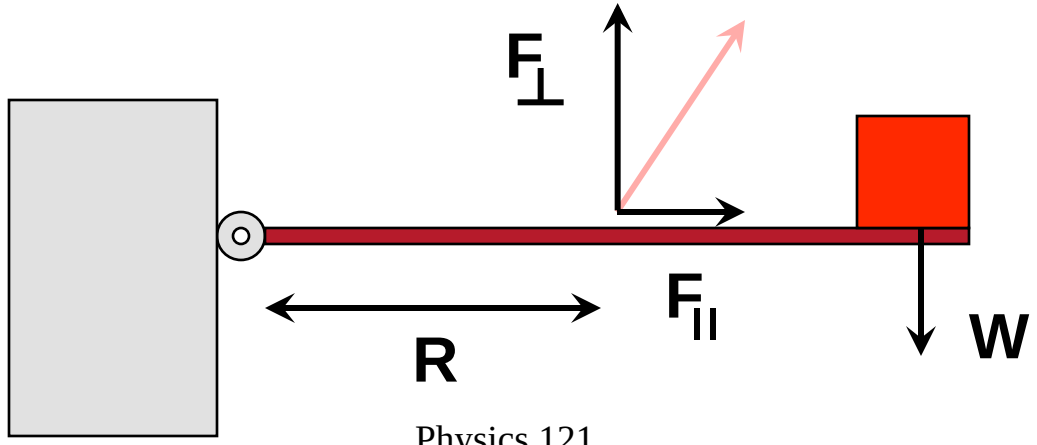
Rotational Effect of Forces: Relevant Factors

- Experimentally, the effect is proportional to the distance from the center.
- The angle at which the force is applied clearly makes a difference with perpendicular being most effective, at another angle less.



Rotational Effect of Forces: Torque

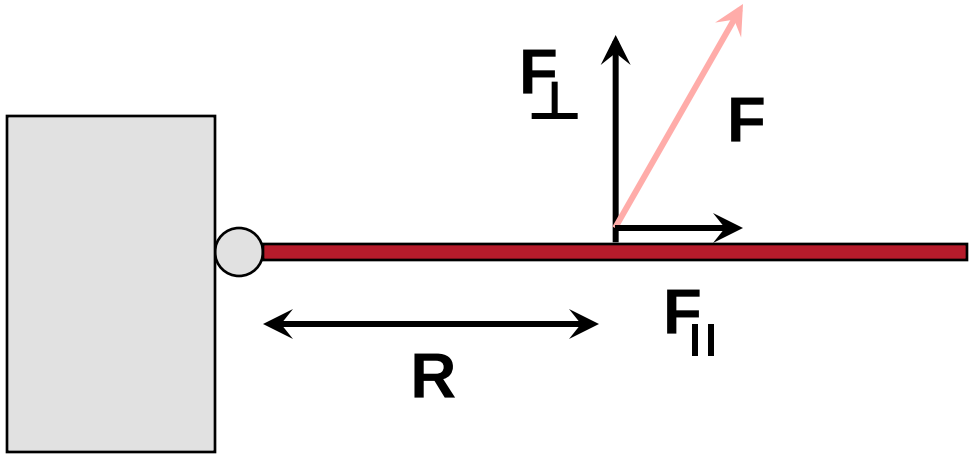
- We can figure out a measure of effectiveness by doing a component decomposition of the force vector:
- Only the perpendicular component has a rotational effect.



Definition of Torque

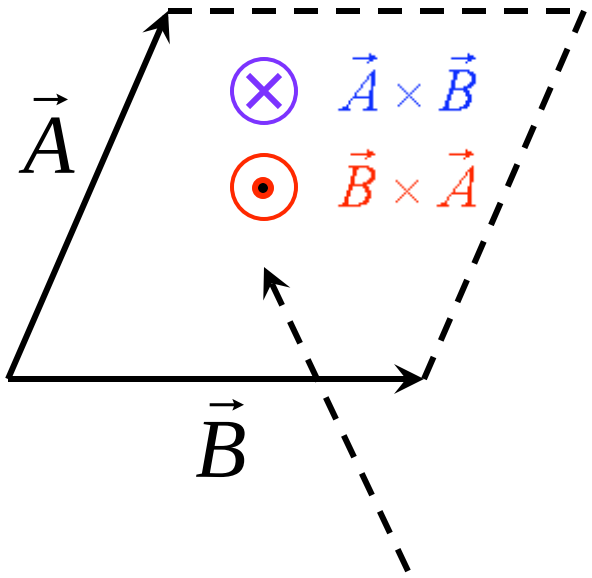
- "Torque" measures the effectiveness of the rotational tendency produced by a force.
- In order for an object not to rotate the torques tending to rotate it opposite ways must balance.

$$\tau = F_{\perp} R = FR\sin\theta$$



The Cross Product

- Just as when we defined the dot product in terms of relevant components, we can define a new product, the cross product, which takes 2 vectors and gives back a new vector.



- We take the magnitude of the cross produce = area and the direction of the cross-product = perpendicular to the area spanned by the two vectors (selected by a RH rule).

Rotation as a Vector

- Torque tends to produce rotation and the direction of rotation matters.
- Choose the direction associated with a rotation as pointing along the axis of rotation with a right hand rule to choose up or down.
- (RH Rule: Fingers curl around in direction of rotation and thumb points in the direction of the vector.)

$$\vec{\tau} = \vec{R} \times \vec{F}$$