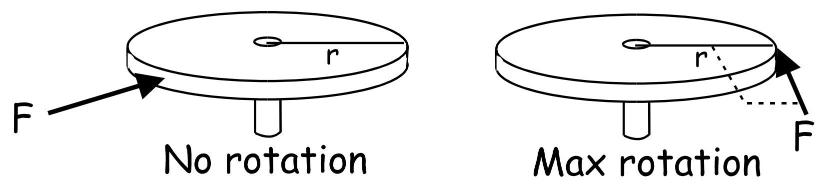
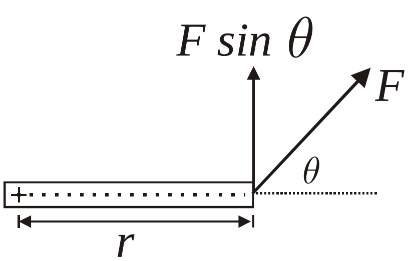
AP Physics – Torque

Forces: We've learned that forces change the velocity of an object. But what does it take to change the ____________________ velocity of a thing? Well, forces are involved, but the force has to be applied in a special way. We call this special applied force a ________________________.

There are many ways to apply a force to a system that can rotate. In the drawing below we have a turntable that can spin. If we just push sideways on the thing, as in the drawing to the left, we will not make it spin. We basically would be trying to tip it over. But if we apply a force tangent to the disc as in the drawing to the right, it will spin. This force is _______________________________________of the circular path. A force that is applied perpendicular to the circular path __________________________ from the spin axis is called a ______________.



The symbol for torque is the Greek letter τ. Torque is given by this equation: [box]



____ is the distance to the center of spin from where the force is applied. This variable is often called the ***lever arm***. Imagine a wrench trying to turn a bolt, the wrench is the lever arm.

______________________ is the force component that is perpendicular to the lever arm.

If the angle _____________________ then the force is __________________________ to the _______________, the sine is 1, & the equation becomes: [box]

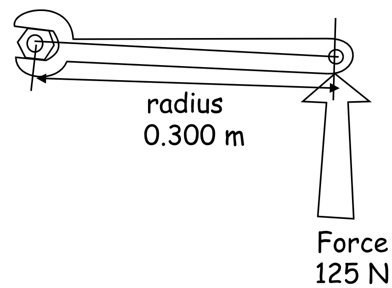
You can see that the unit for torque is going to be a ___________________ • ________________ (____ • ____).

We leave it like that. This looks very similar to the unit for work, the joule, but it is quite different. So energy and work are in joules and torque is left in Newton • meters.

Torque is a ___________________ quantity.

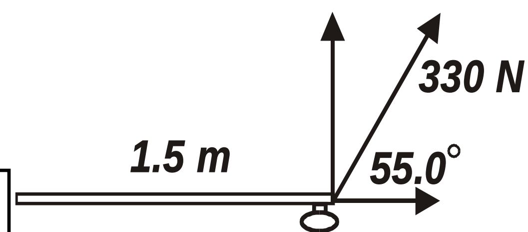
Example Problems:

- 125 N is applied to a nut by a wrench. The length of the wrench is 0.300 m. What is the torque?



- A torque of 857 N•m is applied to flywheel that has a radius of 45.5 cm. What is the applied force?

- You push on the door as shown in the drawing. What is the torque?



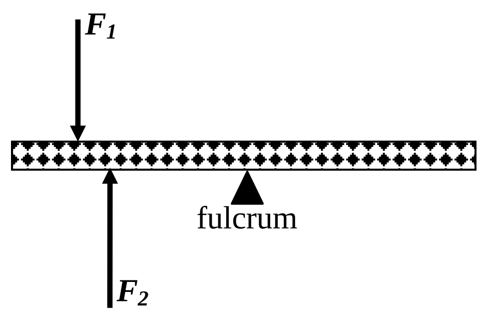
** In order to use __________, the _________________ must be the angle between the _________________________ and the ______________

Multiple Torques: What happens if two or more torques act on an object at the same time?

Two forces are applied to the object in the drawing to the right.

The object is free to rotate about the _______________________.

Both cause a torque.



F_1 causes a CCW (_______________________________________) rotation around the axis.

F_2 causes a CW (________________________) rotation around the axis.

If a torque causes a ________________________ ***rotation***, it is _______________________.

If a torque causes a _________________________________ ***rotation***, it is _____________________.

The sum of the two torques would be:

Equilibrium and Torque: If an object is in ____, then it is either at ______________ or else it is rotating with a constant ____________________

If an object is in rotational equilibrium, the net torque about any axis is ____________.

This means that the ____________________________________ acting on the object must be ____________.

$$\sum \tau =$$

__________________ equilibrium exists when an object has no motion, either linear or angular. There are two conditions which must exist in order to have static equilibrium:

The ________________________ must be _______ and the _______________________ must be ______.

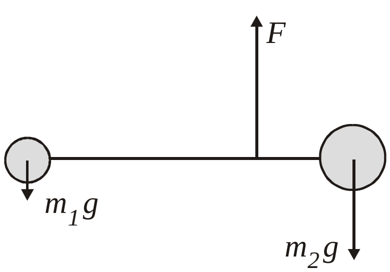
$$\sum F = \qquad \sum \tau =$$

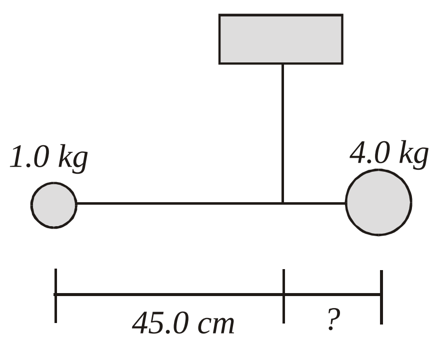
This gives us some very powerful tools to solve static problems. We can analyze a system and look at the forces acting on it, and we can also look at the torques that act on it. We'll be able to do some really cool stuff.

Example Problems:

- Two metal orbs are attached to a very lightweight rigid wire. They are suspended from a rigid point on the ceiling as shown. The system does not move. Calculate the distance from the suspension line to the center of gravity on the right sphere.

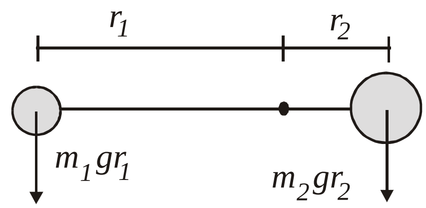
Since the system is at _____________, the sum of the _______________ and the sum of the __________________ must be _______________.





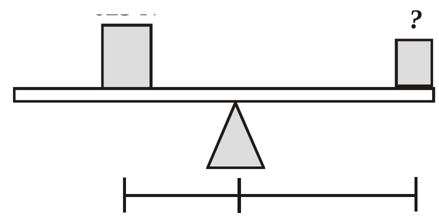
Without using the torque equilibrium, we could not solve the problem. The sum of forces would simply tell us that the upward force would be equal to weight of the two balls.

Using torque, however, allows us to solve the problem.



All we have to do is add up the torques:

- A teeter-totter is in equilibrium as shown. The block on the left has a weight of 625 N and is 1.10 m from the fulcrum. The beam itself has a weight of 32.5 N. What is the mass of the second block if it is placed 3.30 m from the fulcrum on the opposite side of the first block?

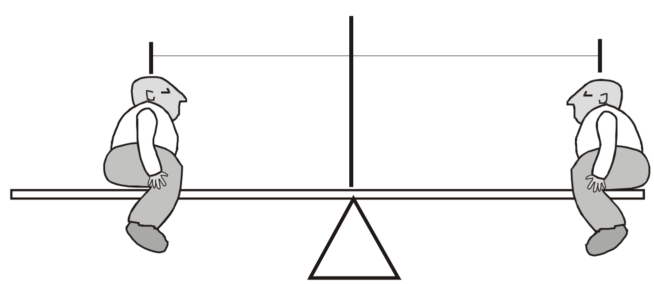


The sum of the torques must be zero:

$$\sum \tau = 0$$

There are three torqes, τ_1 (from the 625 N block) and τ_2 from the other block. The weight of the beam (F_{beam}), even though it has a significant amount of weight, does not cause a torque because the weight acts at the CG of the beam which is also the center of rotation (fulcrum). Thus the lever arm is zero.

- A 50.0 N seesaw supports two people who weigh 455 N and 525 N. The fulcrum is under the CG of the board. The 525 N person is 1.50 m from the center. (a) Find the upward force F_n exerted by fulcrum on the board. (b) Where does the smaller person sit so the seesaw is balanced?



We know that the system is in static equilibrium, so we can analyze the forces. In the *y* direction, the sum of the forces must be zero.

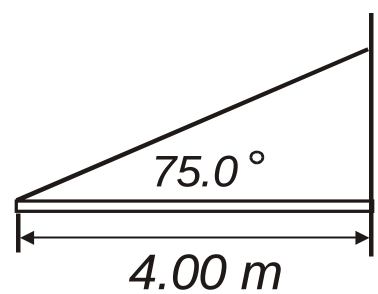
(a) $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are the weight of the two men, $\boldsymbol{F_T}$ is the weight of the teeter-totter, and $\boldsymbol{F_n}$ is the normal force.

Now we can solve for the normal force, this is the upward force exerted on the board by the support stand.

(b) To find the distance the second man must be positioned from the center, we must analyze the torques.

Applying Torque

It is now time to go after some problems that are more complicated.



- A uniform beam is supported by a stout piece of line as shown. The beam weighs 175 N. The cable makes an angle of 75.0° as shown. Find (a) the tension in the cable and (b) the magnitude of the force exerted on the end of the beam by the wall.

We can solve this problem by summing forces and adding up torques.

We have three forces acting on the beam.

The ________________ of the beam which acts at the _______________ of the beam (its CG), _____

The ______________________ in the cable, _____.

And the force exerted by the _____________ on the beam, ______.

(The wall is pushing the beam ________ and ________.)

(a) Let us first sum the torques. The pivot point is the ______________________________ where it meets the wall. Therfore _____ exerts _____________________ as its lever arm is _________. We only have two torques to deal with and, of course, they add up to ___________. Torque one is exerted by the tension in the cable and torque two is caused by the weight of the beam. The force for this torque is applied at the CG, which is at the center of the beam. Only the ________________________________ of the _______________ causes its torque so:

(b) Next we can sum up the forces:

x direction:

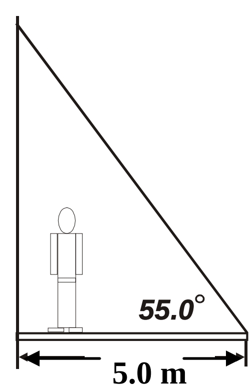
y direction:

We can solve the ***x*** direction equation:

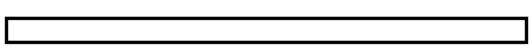
Next we solve the y direction equation:

We've found the x and y components for $\boldsymbol{F_w}$, so now we can find the magnitude of the vector using the Pythagorean theorem:

- A beam is supported as shown. The beam is uniform and weighs 300.0 N and is 5.00 m long. A 625 N person stands 1.50 m from the building. (a) What is the tension in the cable and (b) the force exerted on the beam by the building?



We draw all the forces and distances to each force.



(a) Sum of torques:

(b) Sum the forces in the ***x*** and ***y*** direction. All forces must add up to equal zero.

Fabulous Ladder Problems: Ladder problems are very popular. The basic idea is that you have a ladder leaning against a wall (which is usually frictionless). The ladder is held in place by the friction between its base and the floor it rests upon. We're given the situation and then required to figure out various things – the angle the ladder makes with the deck, the friction force, the coefficient of friction, the force exerted on the top of the ladder by the wall, etc.

- A uniform 250.0 N ladder that is 10.0 m long rests against a frictionless wall at an angle of 58.0° above the horizontal, the ladder just keeps from slipping. (a) What are the forces acting on the bottom of the ladder? (b) What is the coefficient of friction of the bottom of the ladder with the ground?

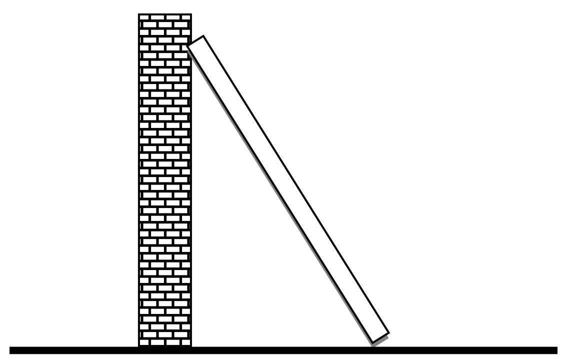
The forces acting on the ladder are: the __________________

of the ladder _____, the ________________________________,

The force the ________________________________ on the ladder

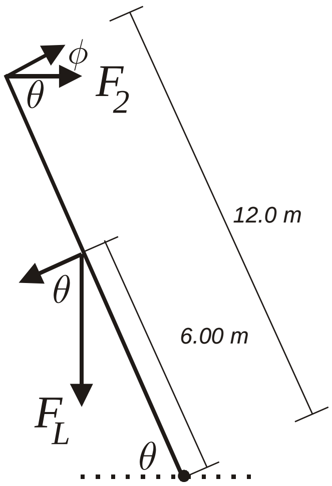
with _____, and the force exerted by the ________________

on the top of the ladder ______.



Now we look at the forces acting on ladder - they have to add up to zero.

The pivot point is the base of the ladder & only the force components perpendicular to the ladder cause torque.



Neither the F_f or F_1 cause a torque as their lever arm is zero.

The weight of the ladder causes a _____________ torque.

The lever arm from F_2 causes a ___________ torque.

The torques add up to ___________

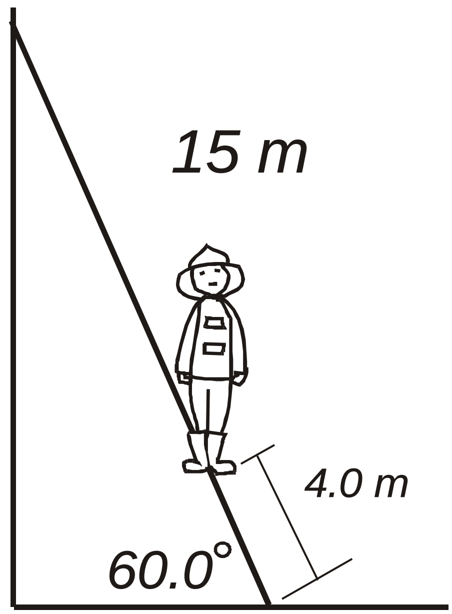
The angle ϕ, using geometry, is clearly going to be:

The torques are:

The frictional force (the other force acting at the base of the ladder is therefore:

(b) Find the coefficient of friction:

- A 15 m, 500.0 N uniform ladder rests against a frictionless wall. It makes 60.0° angle with the horizontal. Find (a) the horizontal and vertical forces on the base of the ladder if an 800.0 N fire fighter is standing 4.0 m from the bottom. (b) If the ladder is on the verge of slipping when the fire fighter is 9.0 m from the bottom of the ladder, what is the coefficient of static friction on the bottom?



(a) Vertical forces

Let's look at torque to find $\boldsymbol{F_2}$:

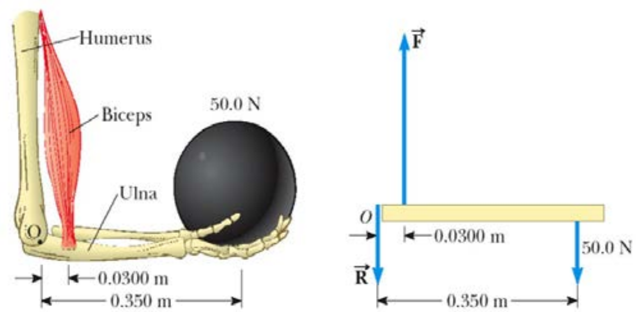
So the force up is ________________

The horizontal frictional force is: ____________________

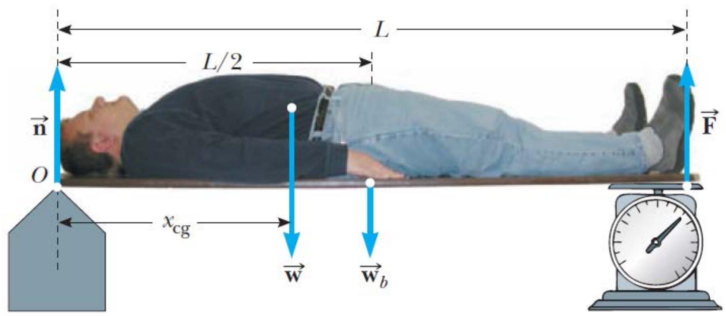
(b) When the fire man is at 9.0 m (we'll figure this from the bottom of the ladder), then we can use the same equation as we used to find F_2 since the only thing that has changed is the distance of the firefighter from the bottom of the ladder.

We can now find the coefficient of static friction for the bottom of the ladder and the deck.

- A 50 N ball is held in a person's hand with the forearm horizontal to the ground. The bicep muscle is attached 0.03 m from the joint, and the ball is 0.350 m from the joint. Find the upward force of the bicep and the downward force (R) exerted by the humerus on the forearm at the joint. Neglect the weight of the forearm.



- Find the center of gravity of the 715 N person from the left end of the board. The length of the person is 173 cm, the board has a weight of 49 N, and the scale reads 350 N.



First we have to pick an ________________________________ (the _________ is sometimes an easy spot).

Now make sure that you use ____ as the ______________________ from the axis of rotation that you choose