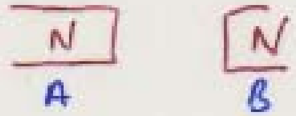
Newton's 3rd Law: Interaction

When 2 bodies "interact" (e.g. collide, or change each other's motion), <u>both</u> are affected:

Both green, purple ball undergo a change in their momenta



don't even have to touch
e.g. magnetic poles repel each other

In fact: both A and B feel the same force, in opposite directions

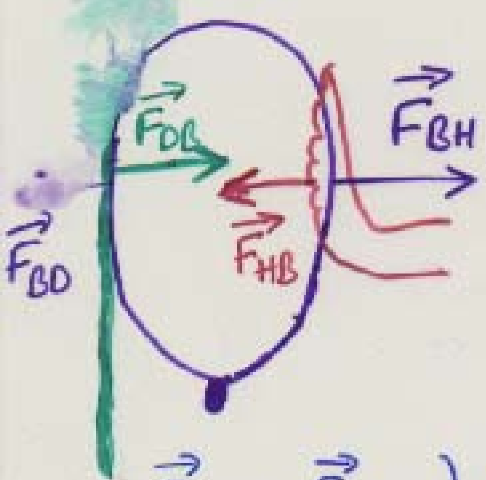
> "To every action (force), there is an equal and opposite reaction" - Newton's 3rd Law

i.e. if A pushes on B with force $\vec{F}_{AB}$, then
B pushes (back) on A 〃 $\vec{F}_{BA} = -\vec{F}_{AB}$

Newton's 3rd Laws ⇒ Forces arise in "interaction pairs"

Statics:

Push balloon against door with hand:



$$\left.\begin{aligned} \vec{F}_{BH} &= -\vec{F}_{HB} \\ F_{BD} &= -\vec{F}_{DB} \end{aligned}\right\}\ \text{Newton III}$$

$$\left.\begin{aligned} F_{BH} &= -F_{HB} \\ F_{BD} &= -F_{DB} \end{aligned}\right\}\ \text{Newton III}$$

If balloon has accel. $a = 0$
then sum of forces on balloon

$$F_{DB} - F_{HB} = 0$$
(Newton II)

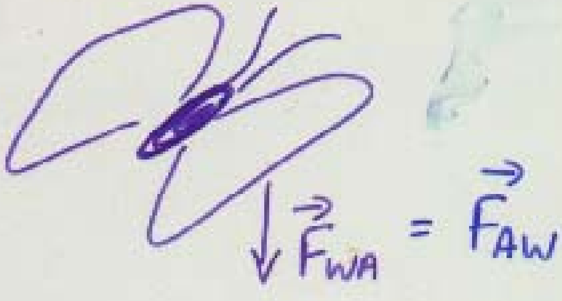
$$\Rightarrow \vec{F}_{BD} = \vec{F}_{HB}$$

i.e. balloon transmits force of hand to the door

Dynamics:

Wing pushes <u>down</u> on air $\vec{F}_{WA}$

⇒ air pushes back up on wing $\vec{F}_{AW} = -\vec{F}_{WA}$



So increase $\vec{F}_{WA}$ ⇒ lifting force $\vec{F}_{AW}$ increases

- lifts butterfly off when $\vec{F}_{AW}$ (upwards) > weight F_W (downwards)

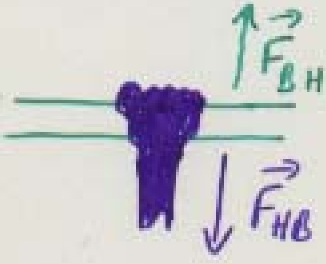
Internal and External Forces

Since forces arise in (equal + opposite) pairs .....

$\Rightarrow$ cannot lift oneself up by belt ! force pair cancels out

but can use an external bar :

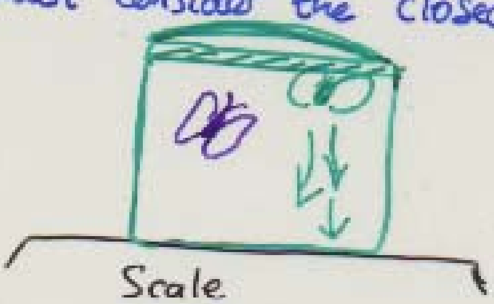
$\vec{F}_{BH} = -\vec{F}_{HB}$



so push <u>down</u> on bar $\Rightarrow$ bar pushes you upwards.

In general, must consider the "closed system" of force pairs

e.g.

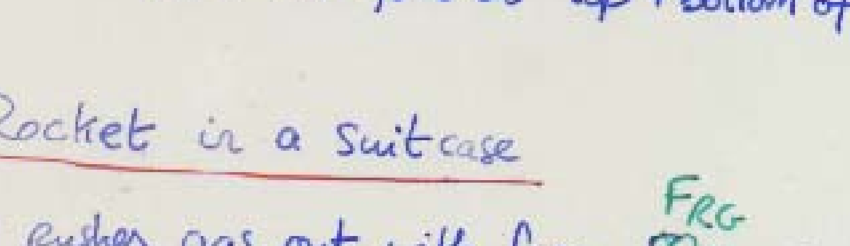


fly or bird can lift off bottom of jar, but cannot lift jar off scale

(i.e. net force on top + bottom of jar = 0)

e.g. Rocket in a suitcase

Rocket pushes gas out with force F_{RG} ~~force~~, so gas pushes back on rocket with $\vec{F}_{RG} = -\vec{F}_{GR}$: rocket accelerates



<u>BUT</u> : enclose system in a suitcase $\Rightarrow$ no external force so suitcase does not move

Newton's Laws and Propulsion

E.g. ①: A rocket expels gas at 600 m/s at a rate of 10 kg/s

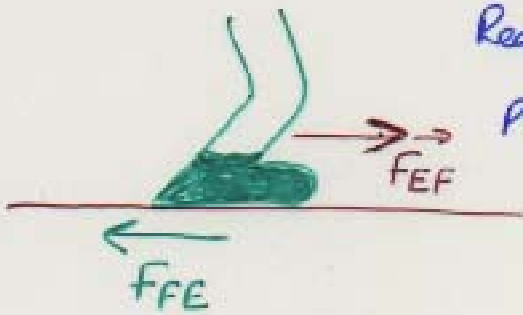
$\Rightarrow$ momentum change of gas in 1s $\Delta mv = 600 \times 10 = 6000$ kg m/s

$\therefore$ Reaction force on rocket $F_{GR} = \dfrac{dp}{dt} = \dfrac{\Delta mv}{1s} = 6000N$

and resulting acceleration $a = F/_{M(rocket)}$

2. Walking:

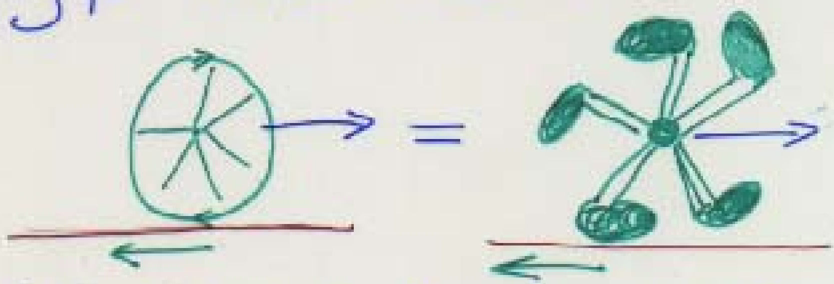
Push backwards on earth with foot $\vec{F}_{FE}$



Reaction force of earth pushes body forwards

$\vec{F}_{EF} = -\vec{F}_{FE}$

3. Similarly for wheel: wheel rim pushes backwards, $\Rightarrow$ reaction pushes axle forwards

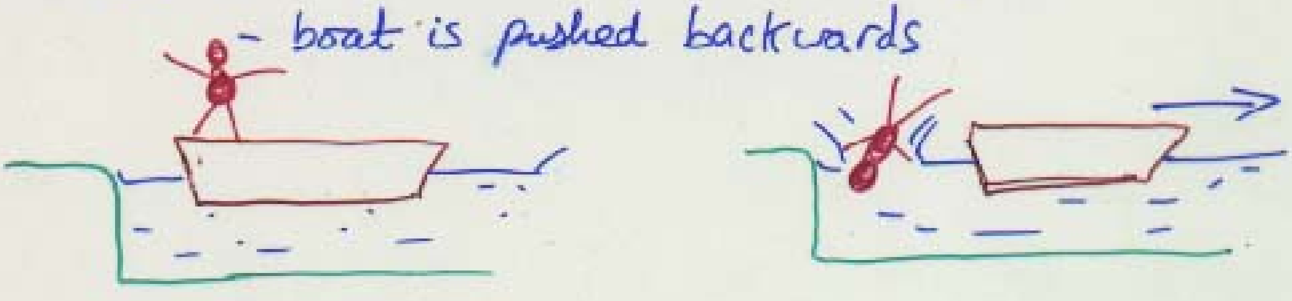


Note: earth's motion is affected, but since $M(earth) >> M(you)$

$\Rightarrow$ for equal forces, your accel $a = \dfrac{F}{M(you)}$ >> earth's accel.

cf. stepping off a boat with $M(boat) \approx M(you)$

- boat is pushed backwards



Gravity, Weight, "Effective Weight"

Weight is NOT Mass! Mass: measure of inertia
$\propto$ quantity of matter (kg)
has same value even in zero gravity

Weight is a **force** $\vec{F}_W = m\vec{g}$ (Newton)

- depends on local gravity (c.f. moon)
- on Earth, bath scales convert from F_W to m assuming $g = 9.81\ m/s^2$

$\therefore$ on moon with $g_m \sim \frac{1}{6}g$, scale reads lower.

"**Effective Weight**" = reading on bath scale
$\propto$ "feeling" of weight
= reaction force of surface F_N

e.g. Place scale on floor of elevator car

$\uparrow \vec{a} = \dfrac{\vec{F}_{tot}}{m}$

For upwards accel. = a

total force $\vec{F}_{tot} = m\vec{a}$

i.e. $ma = (F_N - \underbrace{F_W}_{mg})$

$\Rightarrow F_N = ma + mg$

$\therefore$ if $a > 0$ (up), eff. weight $F_N = m(a+g) > mg$

if $a < 0$ (down), $F_N < mg$

and for free-fall, $a = -g$ .... ?

Weight : Force of Gravity

On earth, all objects accelerate at $g = 9{\cdot}81\,m/s^2$ downwards. Newton's I and II tell us this is due to the force of gravity F_W = mass × accel. = $\underline{mg}$

i.e. $F_W \propto$ mass (not true for all forces)

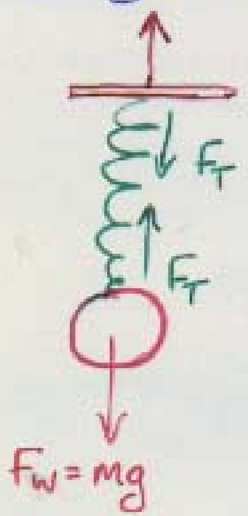
[Note: On moon, Mars etc., mass of object unchanged, but WEIGHT F_W depends on gravity e.g. $g_{MOON} \approx 1/6\,g$]

Near earth, every mass is subjected to force $F_W = mg$ all the time.

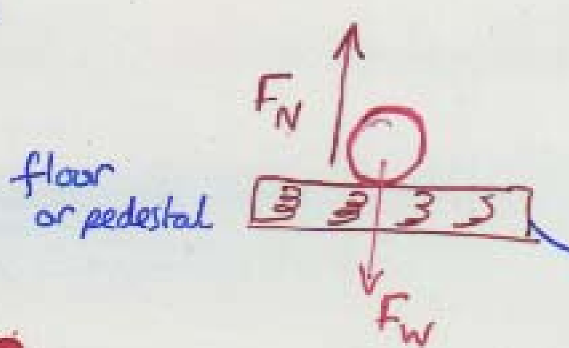
So for non-accelerating objects ($v=0$ or constant, not falling!)

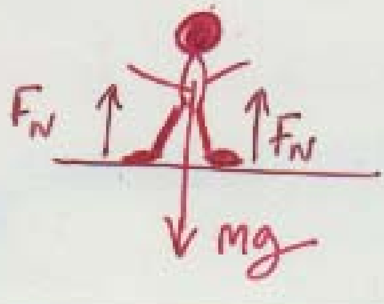
$\Rightarrow$ must be a counterforce opposing weight:

Spring or rope



Normal force ⊥ surface





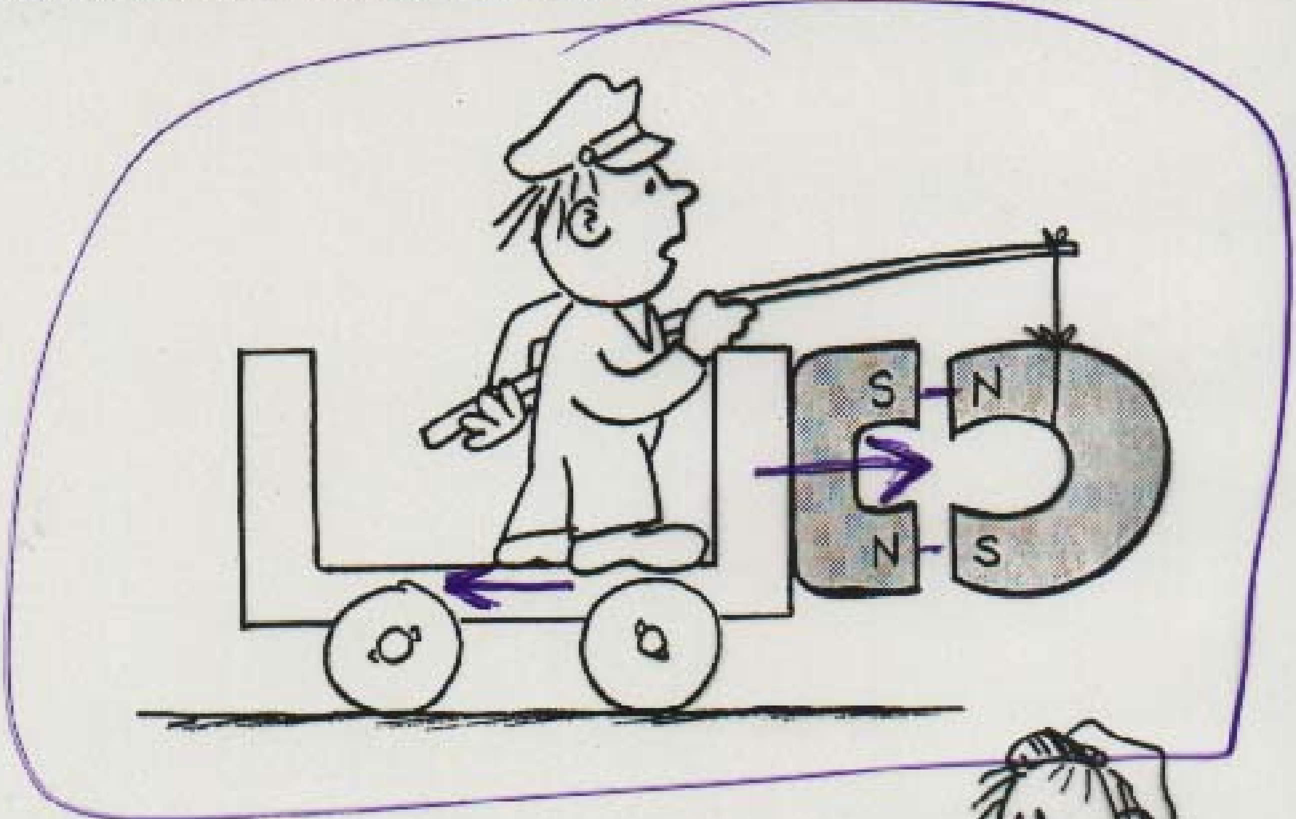
at rest, ground pushes up on each foot: $2F_N = F_W = mg$

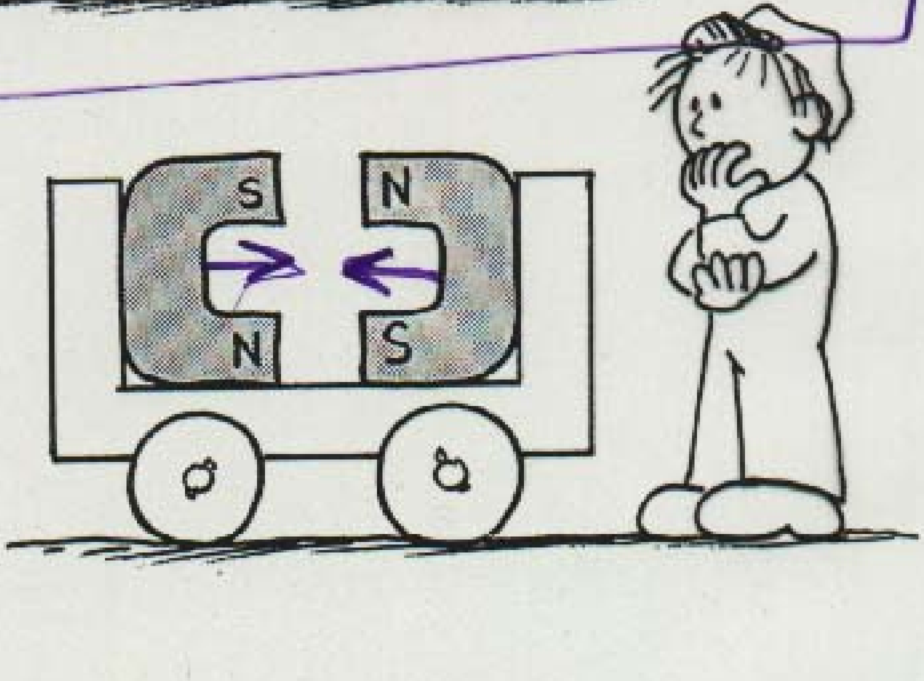
$\Rightarrow F_N = mg/2$.

ANSWER: MAGNET CAR

The answer is: c. You could just dismiss the thing by saying that no work output will result from zero work input — or perpetual motion is impossible. Or you could invoke Newton's Third Law: the force on the car is equal and opposite to the force on the magnet — so they cancel out. But these formal explanations don't illustrate why it will not work.

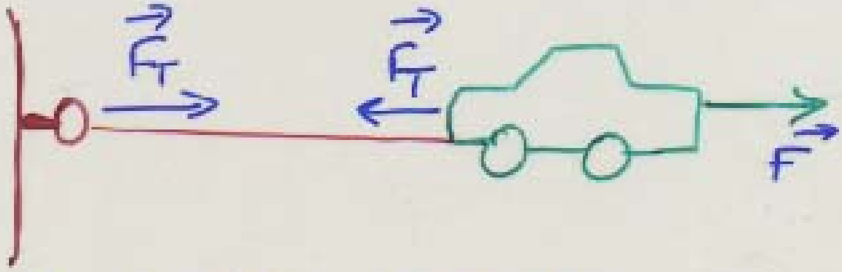
To see intuitively why it will not work, improve the design by putting another magnet in front of the car. Then, to streamline things, put the magnets in the car. Then comes the question: which way will it go?





Tension in Springs, Strings and Ropes (Pulleys)

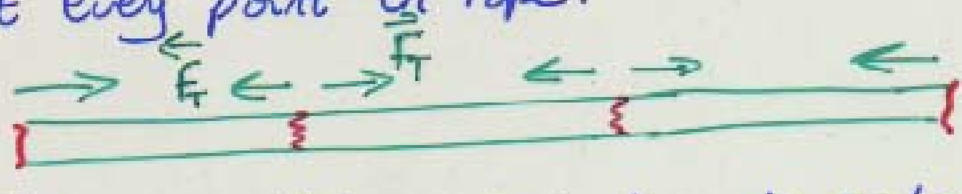
When rope is stretched, it transmits force from one end to other via tension. e.g. car tries to pull down wall



At equilibrium (static), rope pulls against car with equal + opposite tensile force $\vec{F}_T = -\vec{F}$

Now, at other end of rope, rope pulls against wall with force F_T, in direction of $\vec{F}$.

- In a single rope/wire/spring, tension is constant throughout length
- Consider tension to give rise to equal, opposite tensile forces at every point in rope:



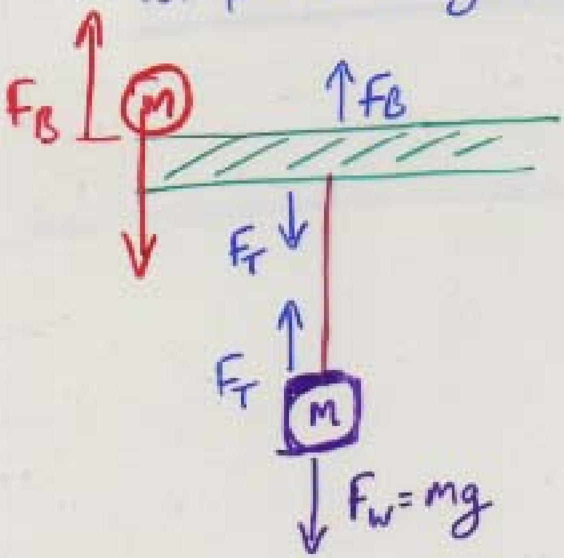
∴ At ends, "un-balanced" F_T acts in towards center.

Break rope at any point → new ends accelerate apart.

Tension is not a force – tension merely moves point of application of force (e.g. moves car away from wall).

Tension + Compression under Gravity : Statics

e.g. hang weight from beam, vs. place weight on beam vs. place weight on pedestal on beam.



At equilibrium (no acceleration so no net force)

For mass m: tensile force $F_T = F_W = mg$

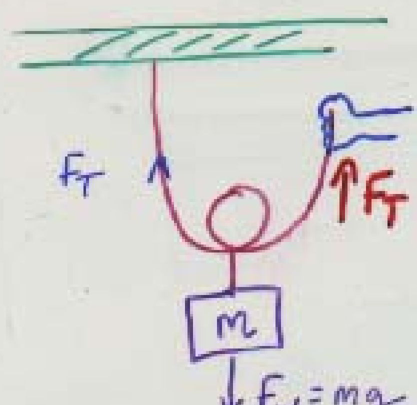
$\therefore$ at beam, F_T down balanced by F_B (up) : $F_B = F_T$

$\therefore$ Force of beam supporting mass $F_B = F_T = F_W = mg$

i.e. string moves point-of-application of the ball's weight

A Pulley allows smooth change-of-direction of F_T:

e.g.



At eqm. for pulley block

$F_W = mg$ (down) $= 2F_T$ (up)

$\Rightarrow F_T = \frac{1}{2}mg$, hand supports $\frac{1}{2}$ the weight, beam supports other half.

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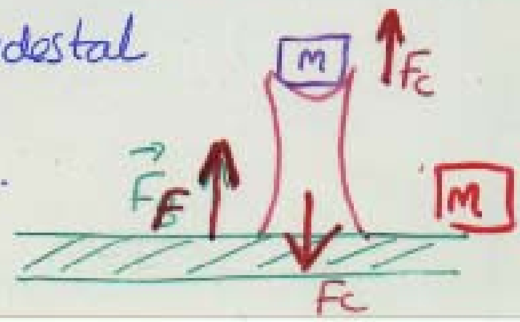
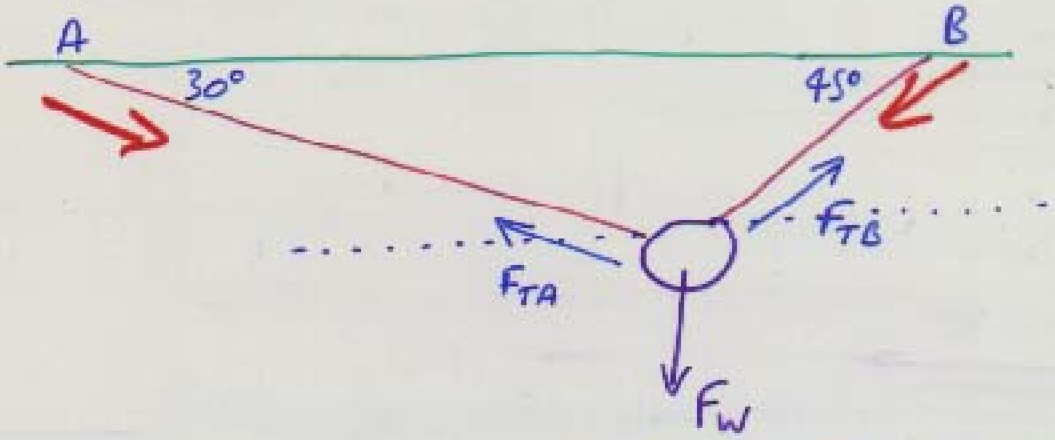
c.f. Compression force transmitted by pedestal

Bar must still support $F_B = F_C = F_W = mg$.



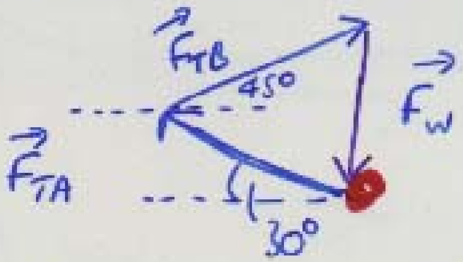
Statics Example: 8kg bowling ball suspended from beam by 2 unequal-length cables, angles 30°, 45° to horizontal.

Find the tension in each wire, and total downward force on beam



At equilibrium, total force on ball $\vec{F} = \vec{F}_{TA} + \vec{F}_{TB} + \vec{F}_W = 0$ (no accel.)

Vector diagram:



Taking components: horizontal $\Rightarrow$ $F_{TB}\cos 45° - F_{TA}\cos 30° = 0$

i.e. $F_{TB} = F_{TA}\dfrac{\cos 30°}{\cos 45°} = \sqrt{\tfrac{3}{2}}\, F_{TA}$ (1)

vertical: $F_{TB}\sin 45° + F_{TA}\sin 30° = mg = 80N$ (2)

Subs (2) into (1) $\Rightarrow$ $F_{TA} = 58.56N$, $F_{TB} = 71.72N$

Note: total force on beam = $F_{TA}\sin 30° + F_{TB}\sin 45° = 80N$, as expected.