Chapter 4: Dynamics

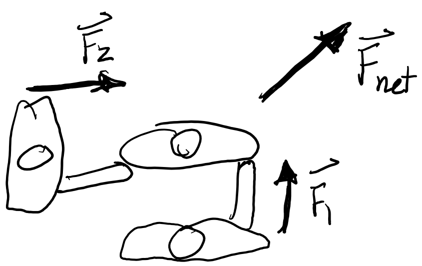
Tuesday, June 15, 2021 12:54

previously: kinematics - study of motion <u>without</u> considering its causes.

<u>now</u>: <u>dynamics</u> - study of forces
↳ what makes things move

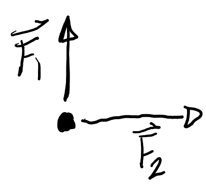
Newton's 3 Laws of Motion

<u>force</u> - a push or a pull (a vector)
unit: newton (N) $1\,N = 1\,kg \cdot m/s^2$



$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2$$

we want a simpler diagram that just shows what is important. <u>free-body diagram</u>



<u>external force</u> - a force acting on a body (or system) from the outside.

<u>4.2</u> <u>Newton's 1st Law</u> - "an object in motion will stay in motion with constant velocity, and an object at rest will stay at rest, <u>unless</u> acted upon by a net external force."

if there is no force, then the object moves with constant velocity (velocity might be zero).

<u>inertia</u> - the property of having constant velocity

- there is a reason for objects to <u>NOT</u> move in a straight line (with constant speed).

(Friction)

why do falling objects get faster? there is some force (gravity)

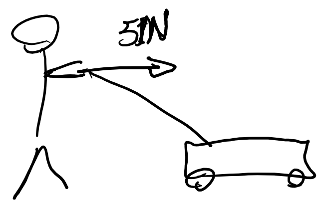
(we sometimes call the first law the "Law of Inertia")

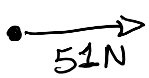
<u>4.3</u> <u>Newton's second Law</u> - "$\vec{F} = m\vec{a}$"

net external Force mass acceleration

<u>mass</u> - a measure of inertia, i.e. how hard is it to change this objects velocity. (unit: kg)

e.g. I push my lawnmower. I can exert a force of 51N and the lawnmower has mass 24 kg. How much does the lawnmower accelerate?





free body diagram

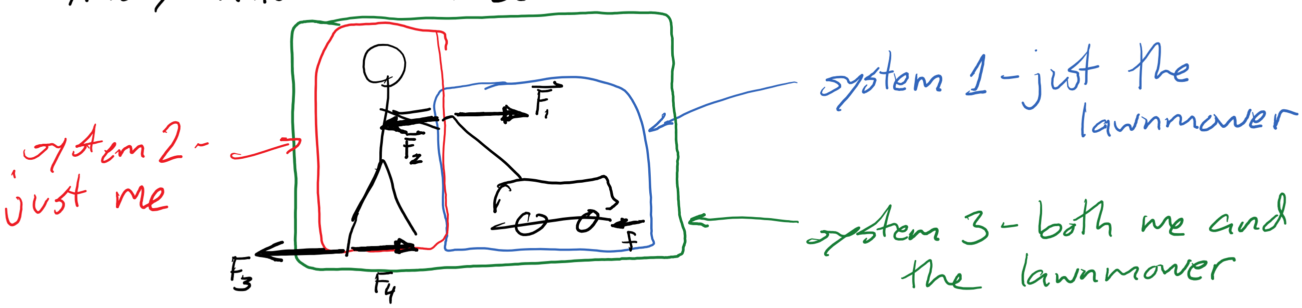
$\vec{F} = m\vec{a}$

$$51\,N = (24\,kg)\,a$$

$$\boxed{a = 2.1\ m/s^2}$$

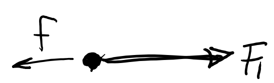
$$\left[\ \text{acceleration of system} = \frac{\text{net external force}}{\text{total mass of system}}\ \right]$$

<u>system</u> – the object or set of objects we want to find / know the acceleration of.



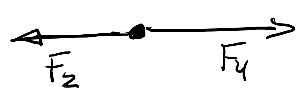
F_1 – me pushing lawnmower $\quad (F_1 = -F_2)$
F_2 – lawnmower pushing back on me
F_3 – me pushing against ground $\quad (F_3 = -F_4)$
F_4 – ground pushing back on me

<u>system 1</u>



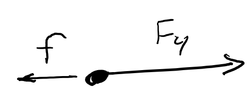
$F_{net} = F_1$

<u>system 2</u>



$F_{net} = F_4 - F_2$

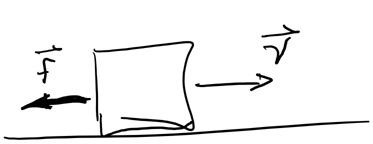
<u>system 3</u>



$F_{net} = F_4$

<u>friction</u> – a force that opposes sliding motion.

(often written as $\vec{f}$)



<u>weight</u> – the force of gravity on an object.

[US imperial units: mass is measured in pounds (lb)
weight is measured in pounds force (lbf)]

WEIGHT $\neq$ MASS

[$W = m\,g$ ← accel. of gravity]

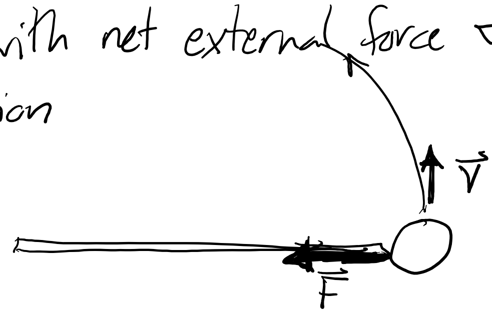
a scale really measures weight. but its readout is in pounds.

weight (in N) = mass (in kg) times $9.81\ m/s^2$.

weight: depends on where you are.

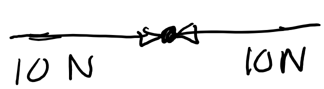
mass: intrinsic – constant for each object.

- Which ~~is~~ correct:
  - a) net force causes motion X
  - b) net force causes change in motion ← ✓
- can you have a system with net external force + constant speed?
  - yes, circular motion



force changes direction of movement, not speed

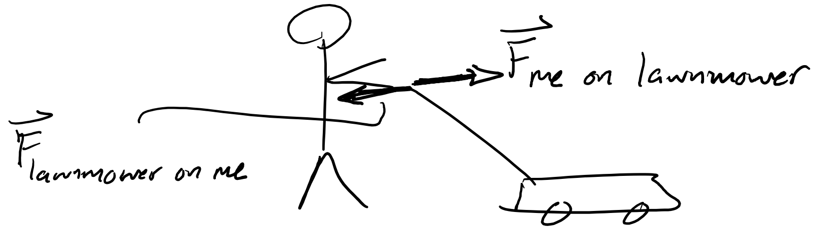
- can you have external forces but no acceleration?
  - yes, they cancel



net external force = 0N

4.4 | Newton's 3rd Law – "For every action there is an equal and opposite reaction."

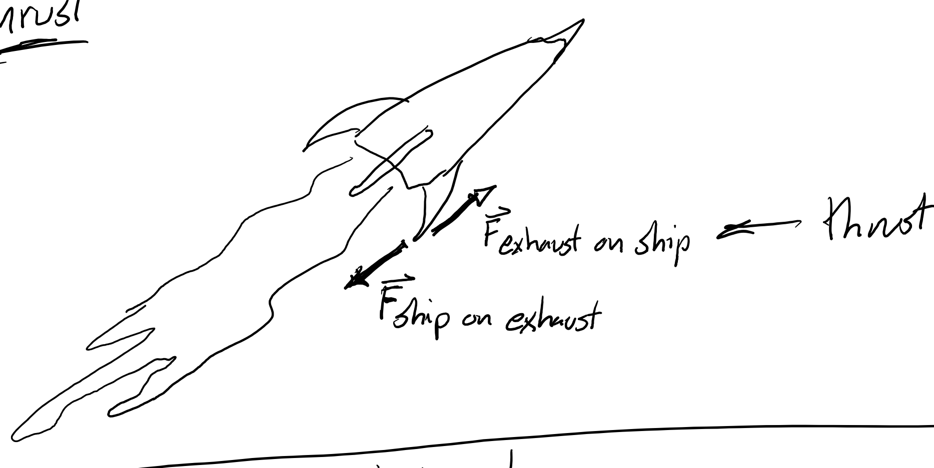
"The force of one object on a second ($\vec{F}_{1 \text{ on } 2}$) is equal in magnitude and opposite in direction to the force of the second object on the first ($\vec{F}_{2 \text{ on } 1}$)"



$$\vec{F}_{\text{me on mower}} = -\vec{F}_{\text{lawnmower on me}}$$

(these opposite forces do not usually cancel, <u>because</u> they are acting on <u>different</u> systems)

<u>thrust</u>

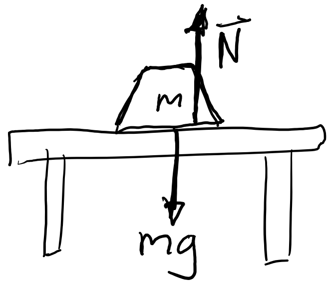


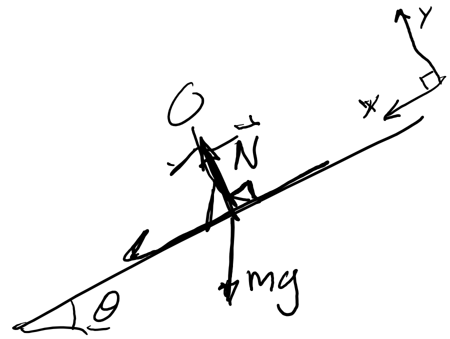
Summary: <u>Newton's Laws</u>

1. objects move with constant velocity (or stay at rest) if there are no external forces.
2. $\vec{F} = m\vec{a}$
3. every action has an equal and opposite reaction.

4.5 **normal force** - force perpendicular to a surface which prevents objects from passing through it.

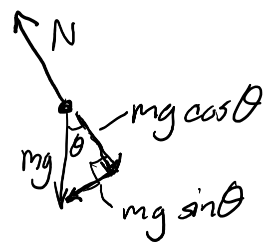
(it is as strong as it needs to be)





$-mg + N = 0$ ← y component of net external force

need to split into components.

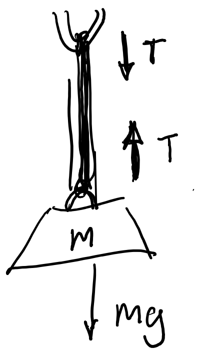


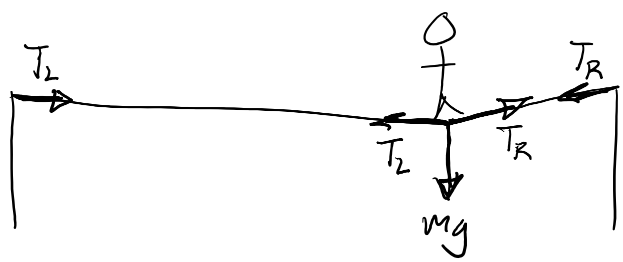
y-component → $N - mg\cos\theta = 0$

x-component → $mg\sin\theta = F_x = m a_x$

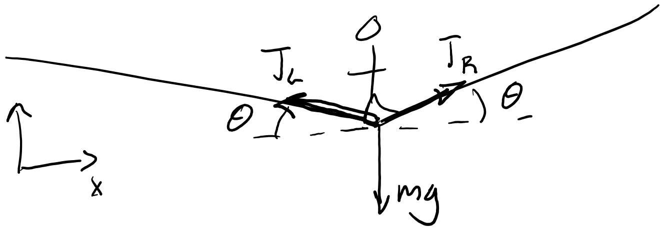
tension - force opposing streaching of e.g. rope

(tension in all parts of a rope is the same)





e.g.



$\theta = 5^\circ$

x: $-T_L\cos\theta + T_R\cos\theta = 0 \longrightarrow T_L = T_R$

y: $T_L\sin\theta + T_R\sin\theta - mg = 0 \longrightarrow 2T\sin\theta = mg$

y: $T_L \sin\theta + T_R \sin\theta - mg = 0 \longrightarrow 2T\sin\theta = mg$

$$\boxed{T = \frac{mg}{2\sin\theta}}$$

$m = 70\text{kg}$

$\theta = 5°$

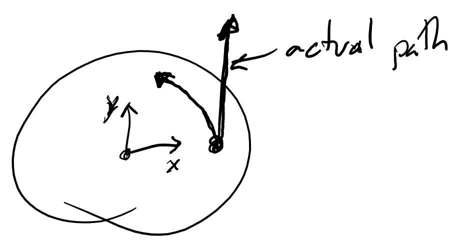
$$T = \frac{(70\text{kg})(9.81\,\text{m/s}^2)}{2\sin 5°} = \boxed{3{,}939\text{ N}}$$

"<u>Ficticious forces</u>" - forces that comes from being in a <u>non-inertial reference frame</u>.

↳ means your coordinate system is accelerating.

e.g. relative to a spinning merry-go-round

<u>centrifugal force</u> - force that appears to push things outward in rotating reference frames (really inertia)



4.6| How to solve problems:

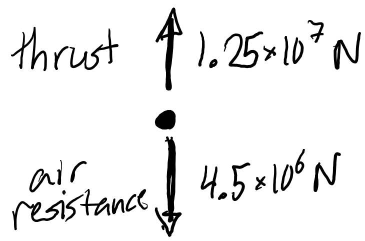
1. identify the system.
2. identify the external forces & draw a free body diagram.
3. calculate net force & apply 2nd law ($\vec{F} = m\vec{a}$).
4. check your answer is reasonable.

once you have acceleration, apply kinematics.
conversely, do kinematics first to get acceleration,

the find force from 2nd law.

e.g. a 5×10^5 kg rocket is accelerating straight up. Its engines produce 1.25×10^7 N of thrust and air resistance is 4.5×10^6 N. what is its acceleration?

system = rocket

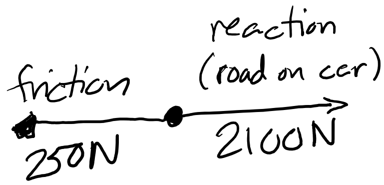


$$F_{net} = 1.25 \times 10^7 \text{ N} - 4.5 \times 10^6 \text{ N} = 8 \times 10^6 \text{ N}$$

$F = ma$ $\quad 8 \times 10^6 \text{ N} = (5 \times 10^5 \text{ kg})\, a$ $\quad \boxed{a = 16 \text{ m/s}^2}$

e.g. the wheels of a car exert a force of 2100N backwards on the road. if the force of friction (inc. air resistance) is 250N and the acceleration of the car is 1.8 m/s^2, what is the mass of the car?

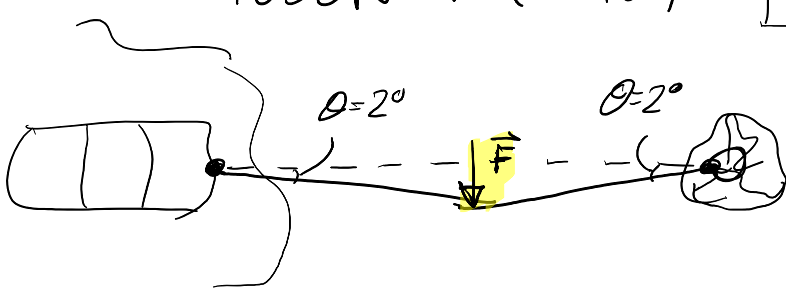
system = car



$$F_{net} = 2100\text{N} - 250\text{N} = 1850\text{N}$$

$F = ma$ $\quad 1850\text{N} = m\,(1.8 \text{ m/s}^2)$ $\quad \boxed{m = 1028 \text{ kg}}$

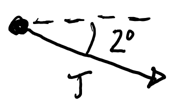
e.g.



what force do you need to apply to make a force of 12,000N on the car if the angle is $\theta = 2°$?

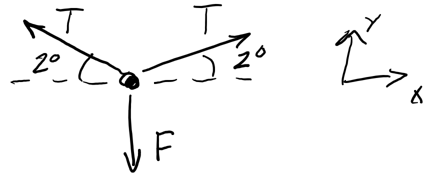
12,000 N on the car if the angle is $\theta = 2°$?

system = car



want $F_{net} = T = 12{,}000\,N$

system = middle of rope



$$y: \; 2T\sin 2° - F = 0$$

$$F = 2(12{,}000\,N)\sin 2° = \boxed{838\,N}$$

4.8 fundamental forces

not contact forces, come from "fields"

e.g. gravity –

mass creates a "field" everywhere
that field makes a force on other masses in it.

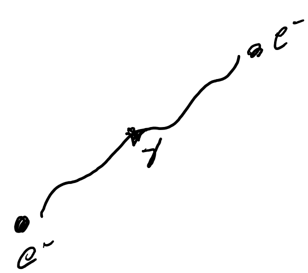
	relative strength	range	carrier particle
gravity	10^{-38}	∞	graviton (undiscovered)
electromagnitism	10^{-2}	∞	photon
weak nuclear	10^{-13}	$< 10^{-18}\,m$	W + Z bosons
strong nuclear	1	$< 10^{-15}\,m$	gluons

General Relativity

– gravity

Standard Model

– electromagnitism
– weak nuclear force



- strong nuclear force