PHY 117 HS2024

Today:

circular motion

integrals = area

forces

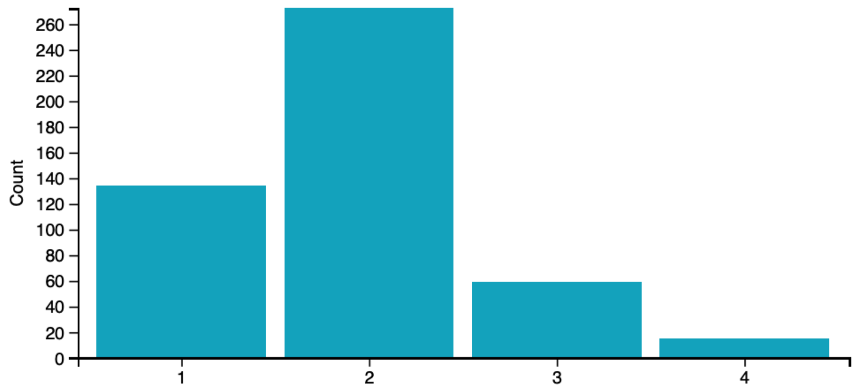
Newton's 3 laws

Week 2, Lecture 1

Sept. 24, 2024

Prof. Ben Kilminster

What is your major at UZH ?



Legend

1: biology
2: biomedicine
3: biodiversity
4: other

Psychology (6)

Software science

Educational sciences

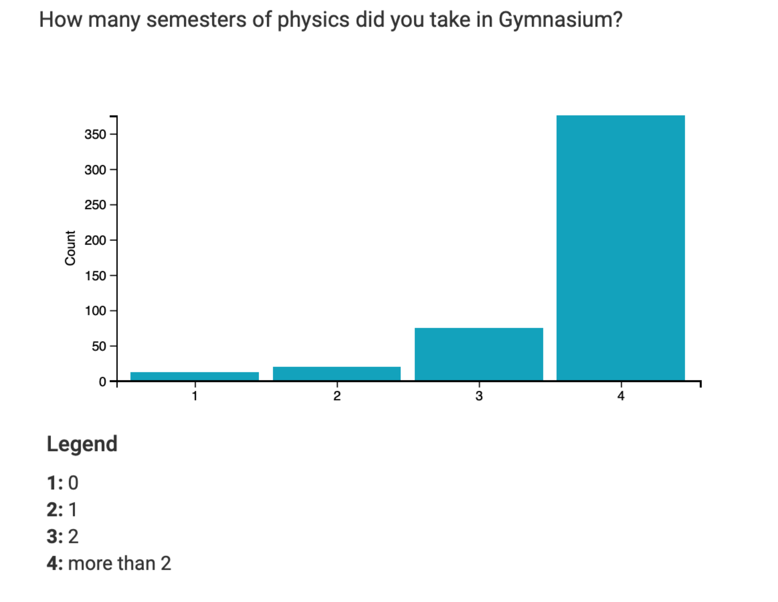
Informatics informatics Computer Science

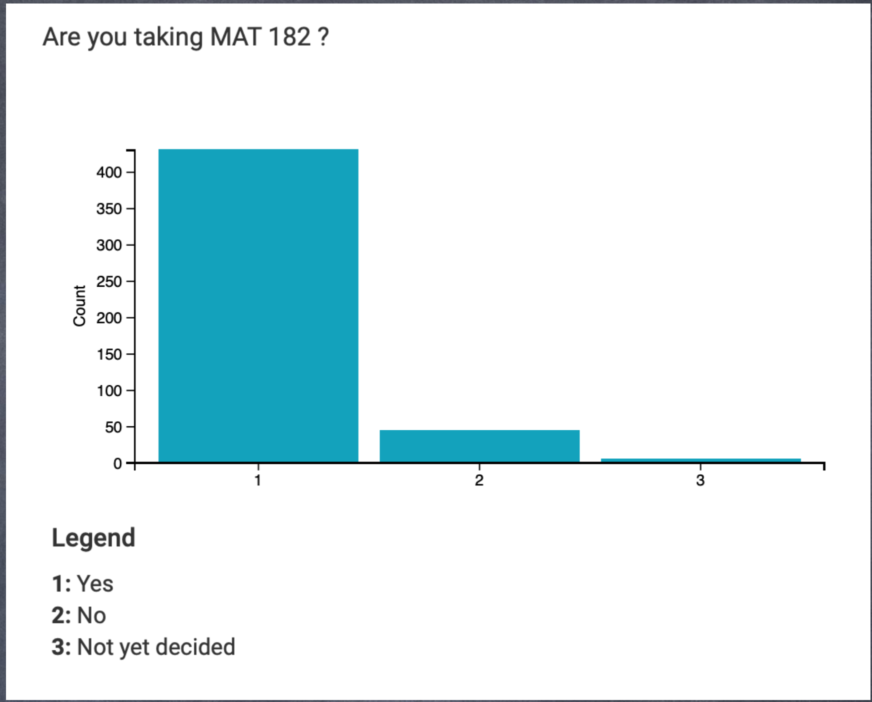
Archaeology

Sociology

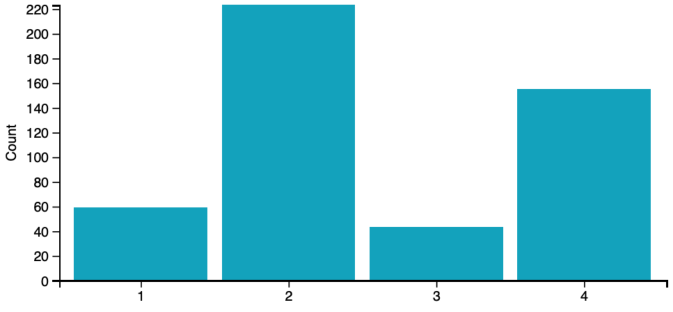
geography

English Literature and Linguistics


How many semesters of physics did you take in Gymnasium?
Count
350
300
250
200
150
100
50
0
1
2
3
4
Legend
1: 0
2: 1
3: 2
4: more than 2


Are you taking MAT 182 ?
Count
400
350
300
250
200
150
100
50
0
1
2
3
Legend
1: Yes
2: No
3: Not yet decided

Which statement fits you best ?



Legend

1: I enjoy physics and I do quite well in it.
2: I enjoy physics but I am not very good at it.
3: I don't enjoy physics, but I do quite well in it.
4: I don't enjoy physics, and I am not very good at it.

Is there something specific you want to learn in physics this semester ?

Some replies:

```
not only understanding but also being
able to complete exercises by myself
```

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Physics related to biomedicine in order to understand
the bigger picture and the physical forces in biology
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```
How to pass the exams
```

```
deeper understanding of electromagnetism
```

```
I Want to understand how everything workshop
```

```
how to get good at physics
```

```
astrophysics topics if possible =)
```

```
Relation of physics with Chemistry
```

```
Nuclear physics, Radioactivity
```

```
Just how things work
```

```
Thermodynamics
```

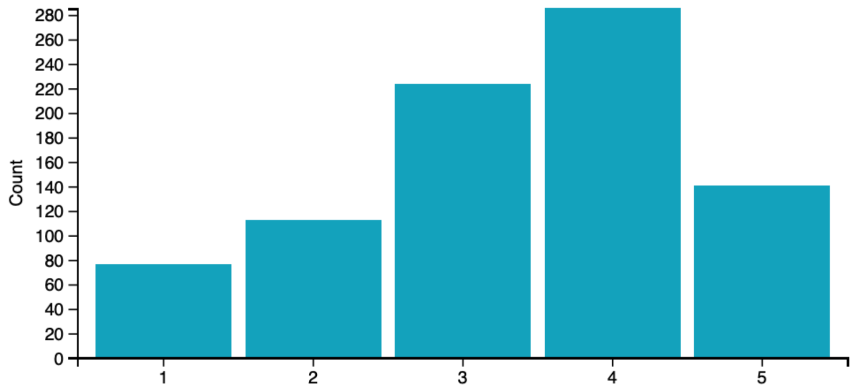
```
Everything 😭
```

```
personally, how to learn physics in an effective way
to achieve best results
```

```
Acceleration in various experiments
Electrical circuit
```

```
Quantum physics, Heisenberg uncertainty principle
```

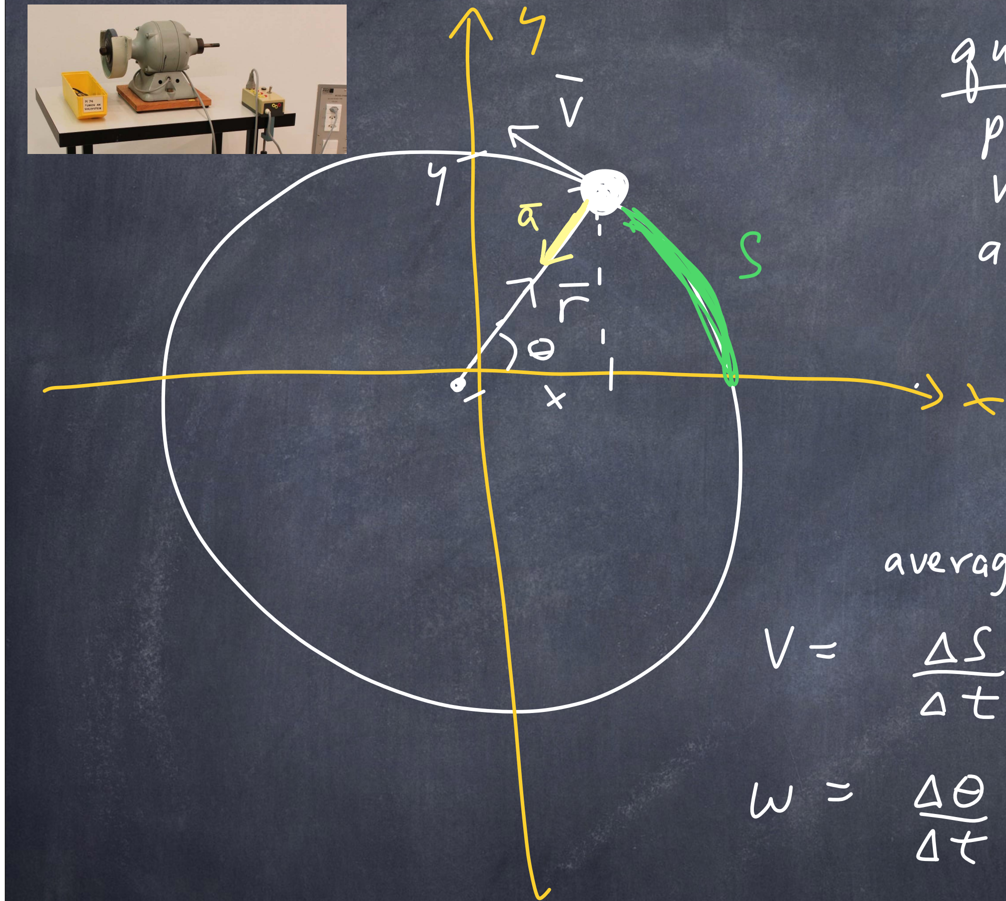
Check all of the following statements that are true



Legend

1: A unit vector has a magnitude of zero.
2: If a particle is moving at a constant velocity, the slope of distance vs. time will be zero.
3: The position of a simple harmonic oscillator repeats in a time of 2*pi/omega.
4: On the moon, a metal ball and a feather thrown from one astronaut to another would have the same parabolic motion.
5: The acceleration of an object moving in a circle points in the same direction as the velocity.

Circular motion (in 2D) at constant speed.



quantity	in terms of distance	in terms of angles	relation
position	s	θ	$s = r\theta$
velocity	v	ω	$v = r\omega$
acceleration	a	α	$a = r\alpha$

$$a = \frac{v^2}{r} = \frac{(r\omega)^2}{r} = \omega^2 r$$

$$\alpha = \frac{a}{r} = \omega^2$$

average → instantaneous

$$v = \frac{\Delta s}{\Delta t} \rightarrow \frac{ds}{dt}$$

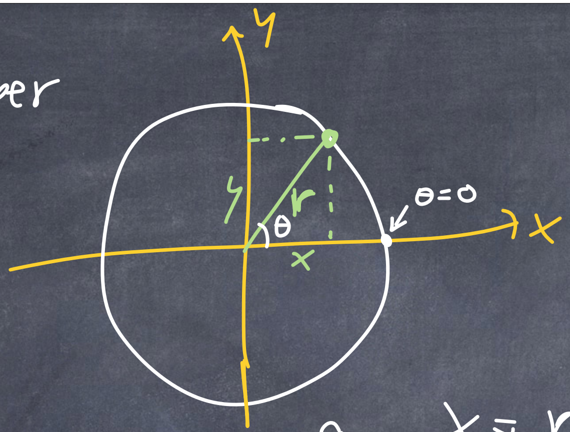
$$\omega = \frac{\Delta \theta}{\Delta t} \rightarrow \frac{d\theta}{dt}$$

$$\alpha = \frac{\Delta \omega}{\Delta t} \rightarrow \frac{d\omega}{dt}$$

Equation of motion for constant speed: $\theta = \omega t + \theta_0$

initial angle

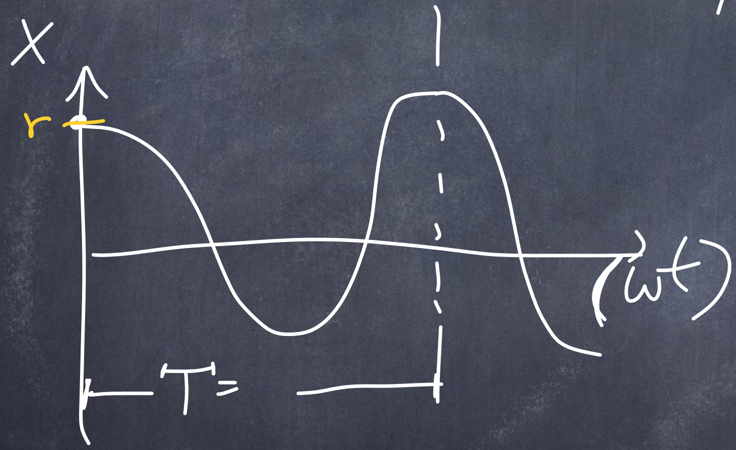
Remember



$$x = r\cos\theta$$
$$y = r\sin\theta$$

If speed is constant, then $\theta = \omega t$

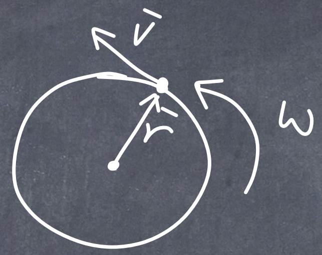
so $x = r\cos(\omega t)$
$y = r\sin(\omega t)$



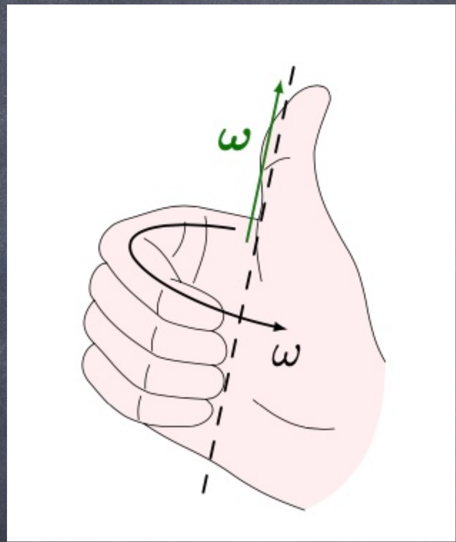
$$T = \frac{2\pi}{\omega} = \frac{2\pi r}{v}$$

Notice: circular motion means x+y components are simple harmonic oscillators.

Direction of $\bar{\omega}$ vector



picture: $\bar{\omega}$ is out of the page



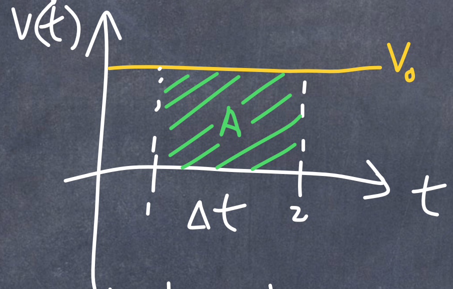
$\odot$ arrow coming towards you

If $\bar{\omega}$ is into the page, we use $\otimes$ (arrow moving away) we have seen that $\frac{dv}{dt} = a$: the slope of v vs. t is the acceleration

$\frac{dx}{dt} = v$: the slope of x vs. t is the velocity

Consider a particle moving at constant velocity:

$v(t) = V_0 = \text{constant}$

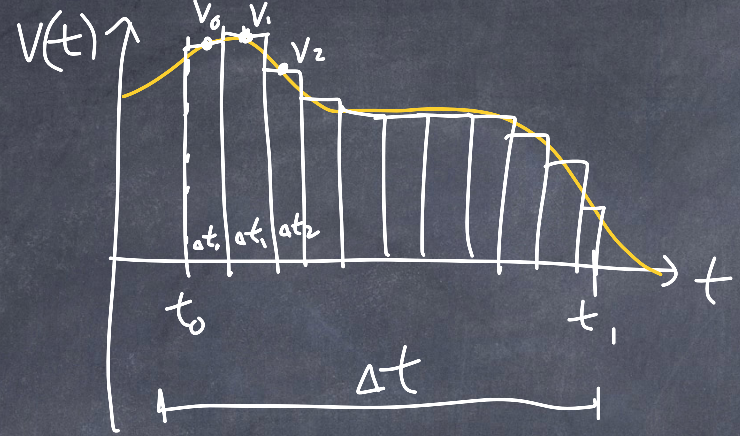


we know that $V_0 = \frac{\Delta x}{\Delta t} \Rightarrow \underbrace{\Delta x}_{t_2 - t_1} = V_0 \Delta t$

from the figure we see that $V_0 \Delta t$ is the area of the rectangle $A = V_0 \Delta t$

So the change in position Δx is the area under the v vs. t curve.

For a more complicated v vs. t curve:



we can approximate Δx by summing up many small rectangles

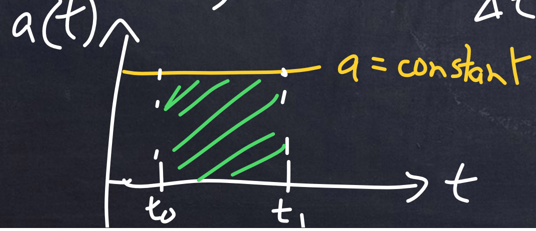
As Δt_i gets smaller, we get more precise

$$x_1 - x_0 = \Delta x = \sum_i v_i \Delta t_i$$

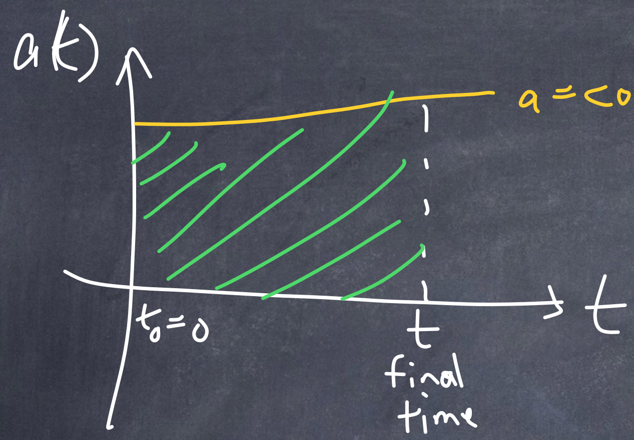
$$\Delta x = \lim_{\Delta t_i \to 0} \sum_i v_i \Delta t_i = \int_{t_0}^{t_1} v\, dt$$

So Δx = the integral of the v vs. t curve from t_0 to t_1

Likewise, $\Delta v = \lim_{\Delta t_i \to 0} \sum a_i \Delta t_i = \int_{t_0}^{t_1} a\, dt$



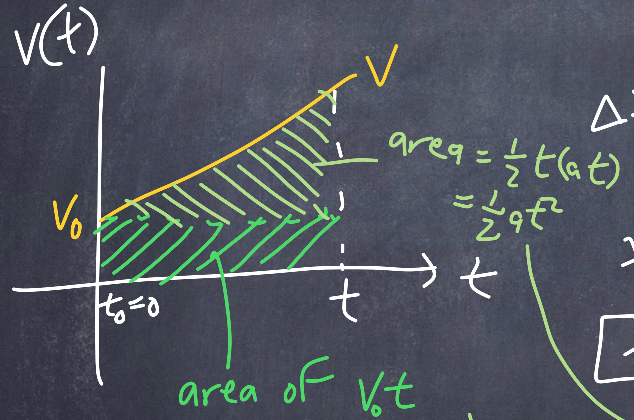
Δv = area of curve under a vs. t



$$\Delta V = V - V_0 = \int_{t_0=0}^{t} a\,dt = at\Big]_0^t = at - 0 = at$$

$$V - V_0 = at \rightarrow \boxed{V = V_0 + at}$$

formula from last week



$$\Delta x = x - x_0 = \int_{t_0=0}^{t} V\,dt = \int_{t_0=0}^{t} (V_0 + at)\,dt = V_0 t + \frac{1}{2}at^2\Big]_0^t$$

$$x - x_0 = V_0 t + \frac{1}{2}at^2$$

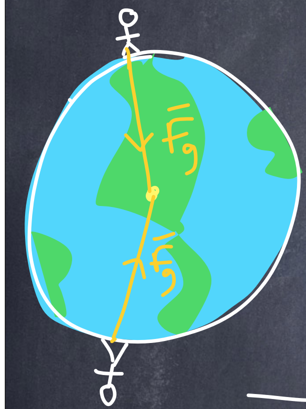
$$\boxed{x = x_0 + V_0 t + \frac{1}{2}at^2}$$

our formula from last week

So starting with a = constant, then we integrated twice, we get our formulas for V + x

Forces: A force is something that pushes or pulls an object.

One of the most common forces is "weight", which comes from gravity.



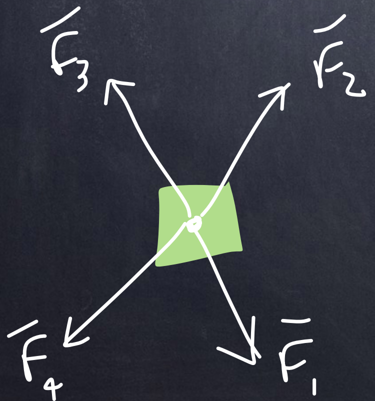
weight $= \bar{F}_g =$ force of gravity $= m\bar{g}$

on earth; mass; $g = 9.81\ m/s^2$

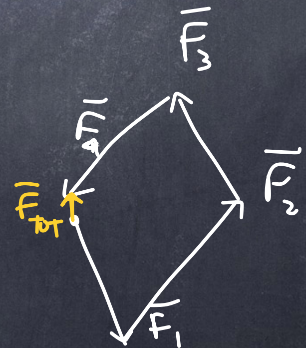
$\bar{g}$ points to the center of the earth

Forces are vectors, and can be added.

$$\bar{F}_{TOTAL} = \bar{F}_{TOT} = \bar{F}_{NET} = \sum_i \bar{F}_i$$



the "tail to tip" method.



If $\bar{F}_{TOT} = 0$,

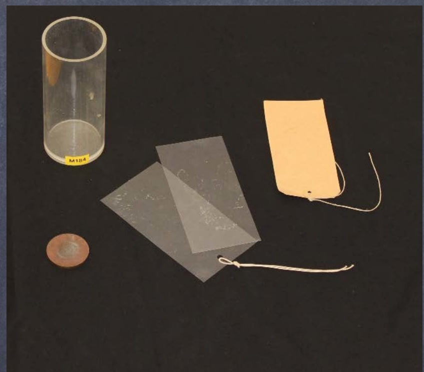
there is no "net" force.

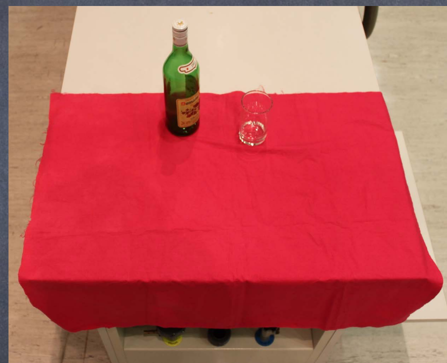
we have equilibrium.

Newton's three laws:

Law of inertia: 1) An object will remain at rest, or continue to move in a straight line unless acted upon by a "net" force

↑ non-zero.

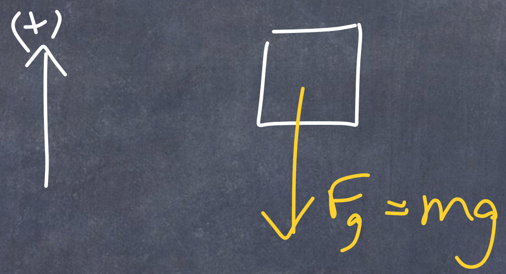




Newton's three laws:

2) A net force will cause an object to accelerate according to $\sum \bar{F} = m\bar{a}$

A common example is a falling object



$$\sum \bar{F} = -\bar{F}_g = -\cancel{m}\bar{g} = \cancel{m}\bar{a}$$

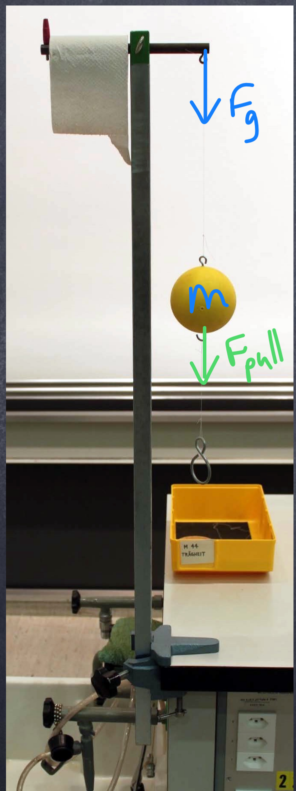
so $\bar{a} = -\bar{g}$

$$\underbrace{\sum F}_{\cancel{m}g} = ma$$

$$\cancel{m}g = \cancel{m}a$$

$$a = g$$

Tests of Newton's first and second laws:



pull quickly: breaks on bottom string, (law of inertia)

pull slowly: breaks on top because there is more force

top: $\vec{F}_g + \vec{F}_{pull}$

bottom: $\vec{F}_{pull}$

toilet paper

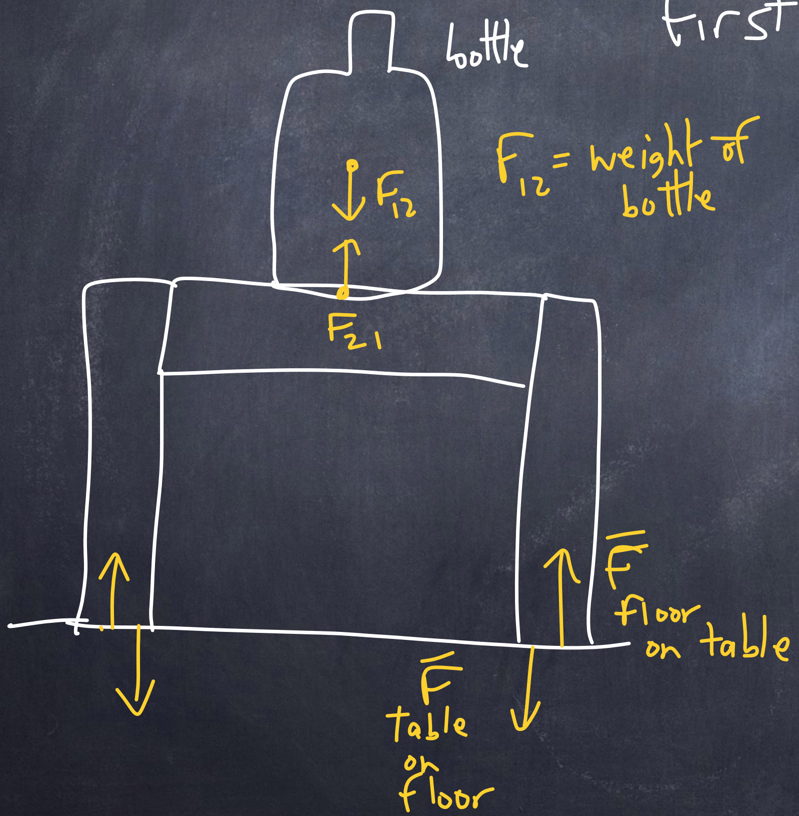
pull it fast : first law

pull it slow : second law

Newton's third law:

$\bar{F}_{12} = -\bar{F}_{21}$

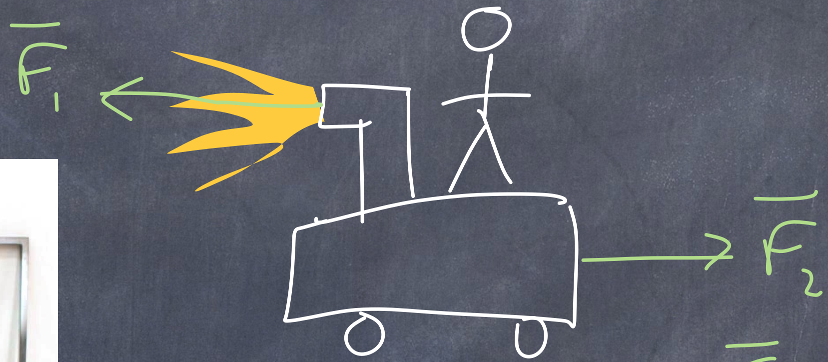
3) when one object exerts a force on a second object, the second object exerts a force equal in magnitude, but opposite in direction, on the first object.



$\bar{F}_{12}$: force exerted by object 1 on object 2.

$\bar{F}_{21}$: force exerted by object 2 on object 1.

third law: action – reaction law



$$\vec{F}_1 = -\vec{F}_2$$

Summary: Newton's three laws:

Law of inertia

1) An object will remain at rest, or continue to move in a straight line unless acted upon by a "net" force

non-zero total force

$\Sigma \bar{F} = ma$

2) A net force will cause an object to accelerate according to $\Sigma \bar{F} = m\bar{a}$

sum

$\bar{F}_{12} = -\bar{F}_{12}$

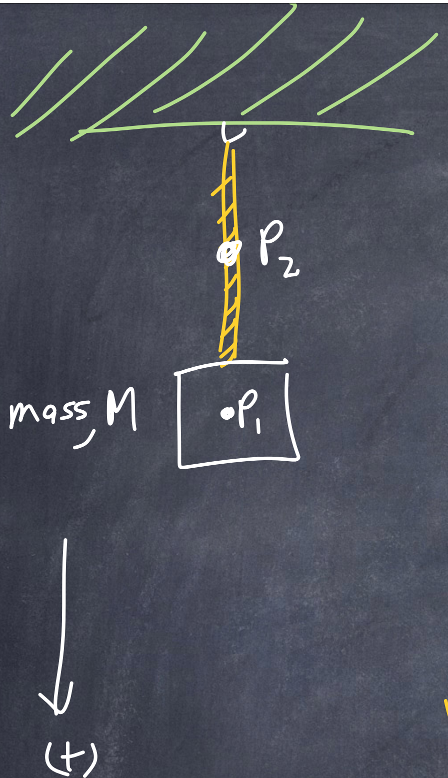
3) When one object exerts a force on a second object, the second object simultaneously exerts a force equal in magnitude but opposite in direction on the first object.

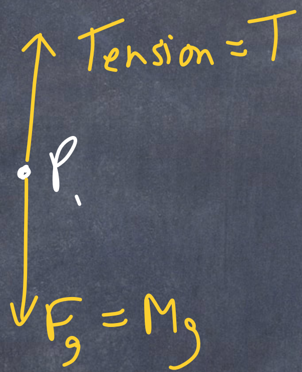
$$\bar{F}_{12} = -\bar{F}_{21}$$

A mass M hangs from a string to the ceiling.

Draw the forces acting on P_1.

Or ... also on P_2 ?





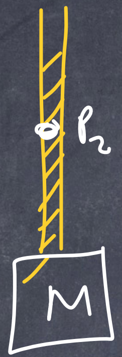
$$\Sigma F = \underbrace{F_g - T = 0}_{T = F_g} = ma$$

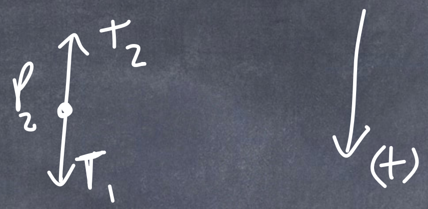
But we must specify the direction + magnitude

$F_g = Mg$ in + direction

$T = Mg$ in − direction

What about P_2 ?





$$\Sigma F = T_1 - T_2 = 0$$

$$T_1 = T_2$$

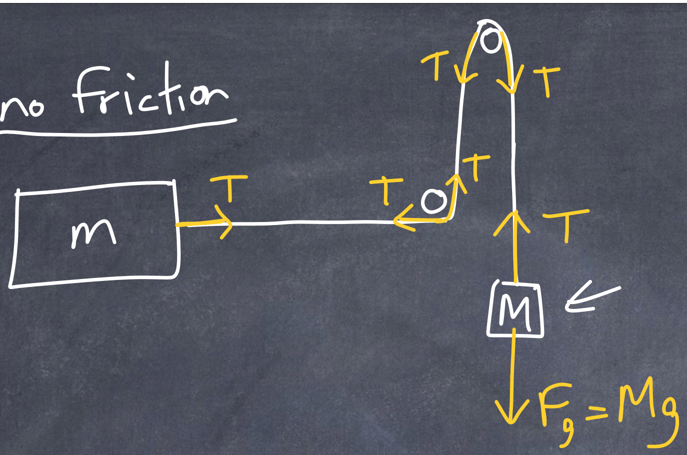
From previous page, we know that $T = Mg$

so here $T_1 = Mg$ in (+) direction

$T_2 = Mg$ in (−) direction.

Tension has the same magnitude everywhere in the string.

assume no friction



$M = 7g$

$m = 227g$

$\Sigma F =$ (total mass) a

$$Mg = (M+m)\,a$$

$$a = \frac{M(g)}{(M+m)} = \frac{(7)(9.81\ \frac{m}{s^2})}{(227+7)} = \boxed{0.293\ \frac{m}{s^2}}$$ predicted

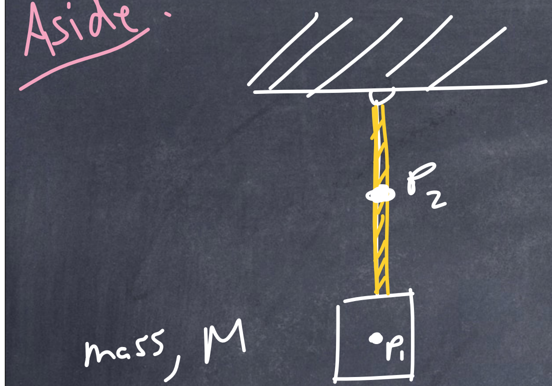
measure $$x = \cancel{x_0}^{\,0} + \cancel{v_0}^{\,0} t + \frac{1}{2} a t^2 = \frac{1}{2} a t^2 \rightarrow a = \frac{2x}{t^2}$$

$x = 1.04\ m$

$t = ? = 2.8 s$

$$a = \frac{2(1.04m)}{(2.8\ s)^2} = \boxed{0{,}265\ \frac{m}{s^2}}$$ measured

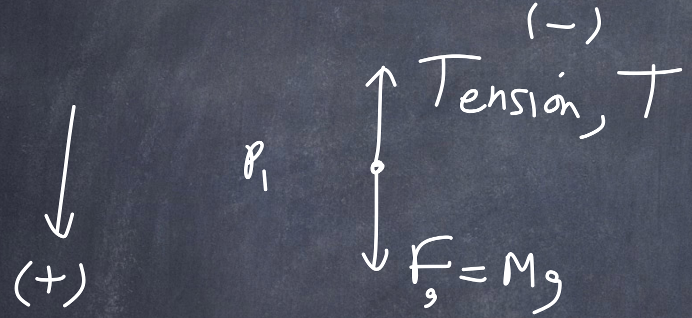
Aside:



Exercise:

A mass M hangs from a string to the ceiling.

Draw the forces acting at P_1.
What about P_2?



If we use vectors for $\bar{F}_g$ and $\bar{T}$, then we don't need to explicitly put negative signs in our sum, $\Sigma \bar{F}$.

$$\Sigma \bar{F} = \bar{F}_g + \bar{T} = 0$$

then $\bar{T} = -\bar{F}_g$

so $\bar{F}_g = M\bar{g}$
$\bar{T} = -M\bar{g}$

If we use T and F_g as scalars, then we need to keep track of negative signs.

We state T is in (−) direction

$$\Sigma F = F_g - T = 0 = ma$$

and $T = F_g$

But we must specify the direction

$F_g = Mg$ in (+) direction
$T = Mg$ in (−) direction

In both cases F_g points down
& T points up.

Aside: Sometimes people write $\frac{df(x)}{dx}$ as $f'(x)$.

These two are the same.

Since $\frac{df(x)}{dx} = f'(x) \Rightarrow df(x) = f'(x)\,dx$

And if you take the integral of both sides:

$$\int d\,f(x) = \int f'(x)\,dx$$

This becomes:

$$f(x) = \int f'(x)\,dx$$

which is the definition of an integral

Also, $\frac{d^2 f(x)}{dx^2} = f''(x)$