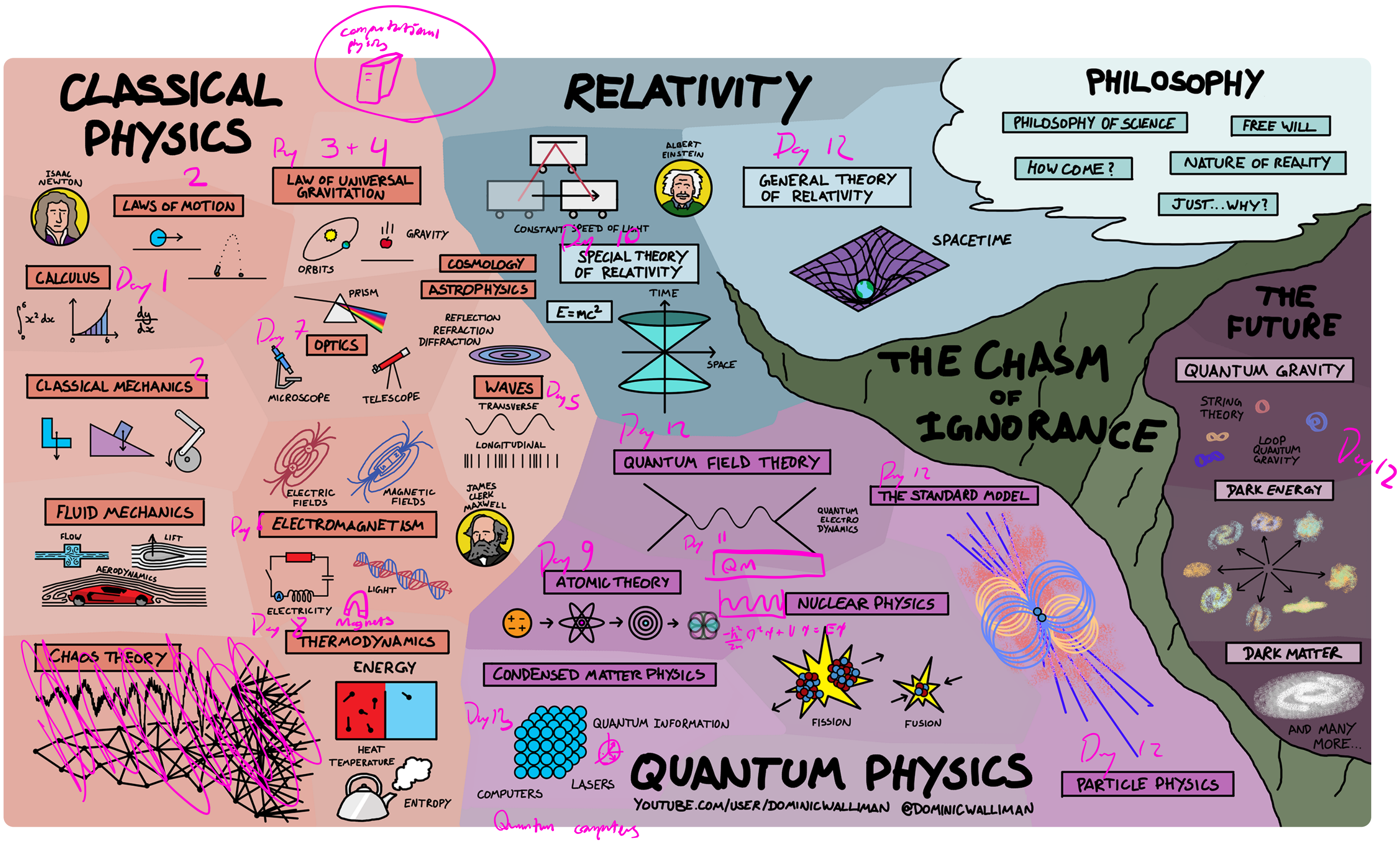
Day 1: intro + preliminary

Introduction + ice breaker (15 min)

ice breaker: 2 truths 1 lie

Map of physics + syllabus (15-20 min)



Quantum computers

Nanofab / optical info. processing

Physical quantities + Units (20-30 min)

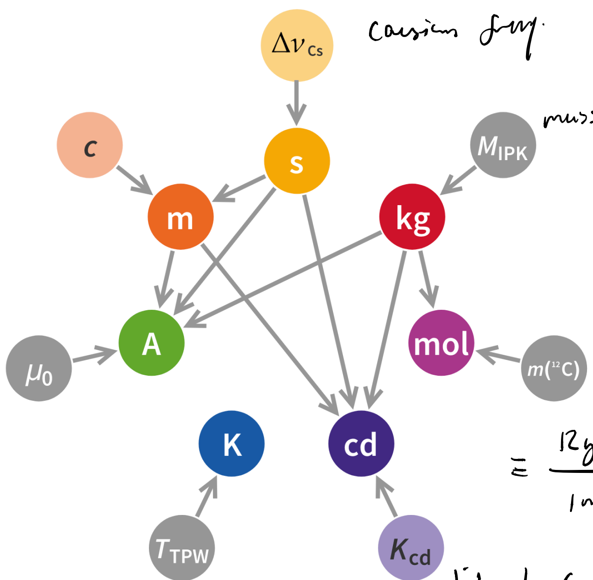
What is a unit?

Units made of combinations of base units

Base unit	Name	Symbol
length	meter	*m*
mass	kilogram	*kg*
time	second	*s*
electric current	ampere	*A*
temperature	kelvin	*K*
luminous intensity	candela	*cd*
amount of substance	mole	*mol*

SI units & May 20, 2019 redefinition

Old SI



cesium freq.

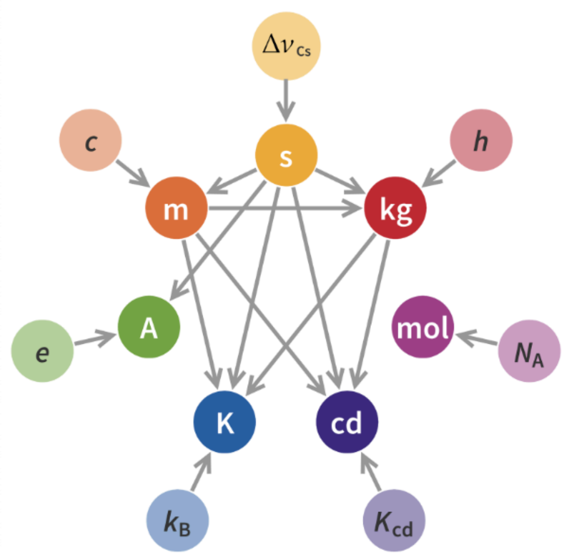
mass of kilo

$1 \frac{g}{mol} = \frac{12g\ C^{12}}{1 mol}$

natural candles

triple point of water

$= 273.16$ K



$k_B \equiv \frac{R}{N_A}$

$K_{cd} \equiv 683 \frac{cd\ sr}{W}$

@ 540 THz light

Units are sanity test

Exercise 1.1 Try to write down the units to describe the following physical quantities in terms of base SI units! (As a bonus, try to estimate reasonable numerical quantities of your units!)

1. The speed of a car on a highway
2. The mass of a dog
3. The rate that water flows through a sink faucet (there can be multiple definitions for this!)
4. The power output of a stove surface
5. The power drawn by a toaster
6. The temperature of a toaster heating element

Unit conversions + Dimensional analysis

It is often necessary to convert from one type of unit to another. Suppose you want to calculate the potential energy of a rock on a hill. As you'll learn soon, the potential energy U is given by $U = mgh$, where m is the mass of the object, g is gravitational acceleration, and h is the height. Suppose that you know m, g, h, but they are all in incompatible units: $m = 10lb$, $g = 9.8\frac{m}{s^2}$, and $h = 2.35 \times 10^{-15}$lightyears. You want to know U in units of Joules = $kg\frac{m^2}{s^2}$.

To do this, we need to determine conversion factors between units. A conversion factor is a ratio expressing how many of one unit are equal to another unit. For example, there are 2.20 pounds in 1 kg, 100 centimeters in 1 meter, and so on.

Now we can set up our unit conversion. We will write the units that we have and then multiply them by the conversion factor so that the units cancel out, as shown:

■ Example 1.1

$$\begin{aligned}
U &= mgh \\
&= 10\text{lb} \cdot 9.8\frac{m}{s^2} \cdot 2.35 \times 10^{-15}\text{lightyears} \\
&= 10\cancel{\text{lb}} \times \frac{1\text{kg}}{2.20\cancel{\text{lb}}} \cdot 9.8\frac{m}{s^2} \cdot 2.35 \times 10^{-15}\cancel{\text{lightyears}} \times \frac{1\cancel{\text{lightyear}}}{9.46 \times 10^{15} m} \\
&= 4.53\text{kg} \cdot 9.8\frac{m}{s^2} \cdot 22.2m \\
&= 985.5\text{kg}\frac{m^2}{s^2} = 985.5\text{Joules}
\end{aligned} \tag{1.1}$$

Mathematical models (10 - 15 min)

In physics we try to write mathematical models to describe how things work. Examples:

- Population growth $P = P_0 \cdot 2^{kt}$
- Ball being dropped: $x = x_0 + v_0 t + \frac{1}{2} a t^2$
- Electrons are like billiard balls
- Gravity is invisible force, $F = G\frac{mm}{r^2}$

Models have limitations

- overpopulation, carrying capacity
- air resistance at high speeds
- Diffractions + double slit experiment
- precession of mercury

Can improve models so they are more descriptive

- $P \sim \dfrac{KP_0 2^{kt}}{K + P_0(2^{kt} - 1)}$
- $x = x_0 + v_0 t + \frac{1}{2} a t^2 - Kv^2$
- wave-particle duality
- general relativity

Continually re-evaluating & refining models is how we got to physics as it is today!

Good models not only fit experimental data but also make theoretical predictions to verify w/ experiment

experiments + observations

make model to describe behavior

new experiments!
new ideas!
test limits of theory!

Estimation (~30 min)

Physics is all about using what you know to figure out what you don't know. Sometimes you have to estimate when you don't know something.

"order - of - magnitude" calculations

Ex 1: What is the mass of the earth?

Given: SFO → JFK is 6hr flight

this amazon question

2 votes

Question: Seeing conflicting/incomplete info in the available answers. What are the actual diameters and thicknesses of the 15 lb and 20 lb weights?

Answer: Dear Wrench,
Thank you for your interest in our product and contacting us.
Weight Plate 15 lbs: 8.90" dia, 1" thickness.
Weight Plate 20 lbs: 9.70" dia, 1" thickness.
We hope that our response answers your inquiry. If there is anything unclear, please don't hesitate to contact us.
Very best regards. see less
By idzo SELLER on December 23, 2016

$$V = \pi r^2 h = \pi \left(\frac{9.7\text{ in}}{2}\right)^2 1\text{ in} = 73.9\text{ in}^2$$

$$\rho = \frac{20\text{ lb}}{73.9\text{ in}^2} = .27\text{ lb/in}^3 = 7.5\text{ g/cm}^3$$

plane travels at ~500 mph

$3/24$ time zones, so earth circumference is $\sim 500\frac{\text{mi}}{\text{hr}} \cdot 6\text{ hr} \cdot \frac{24\text{ time zones}}{3\text{ time zones}}$

$= 24\,000$ mi

$\therefore$ radius is $\frac{24000\text{ mi}}{2\pi} = 3820\text{ mi} \Rightarrow 6.15 \times 10^8$ cm

$\therefore$ mass is $V \cdot \rho = \frac{4}{3}\pi r^3 \rho = 7.28 \times 10^{24}$ kg

actual: 5.97×10^{24} kg (21% off!)

→ what could be improved?

Ex 2: SF goes ~~green~~ brown & changes all energy to horse power. How much \$ to pay workers to clean up all the poop?

Given: 1 horse poops 50 lb/day

SF uses 18000 MWh/day

18 E9 W·hr/day = 7.5E8 W = 1E6 hp = 50e6 lb poop/day

↑ 1 hp = 745 W

Assume 1 worker can shovel 1000 lb/day, need 50e3 workers,

50 × \$15/hr = \$750,000/hr, or

\$750,000/hr × 8 hr/day × 5 day/wk × 50 wk/yr

= \$1.5 billion per year

Ex 3: Choose a problem!

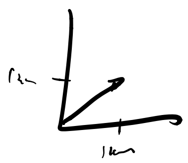
Break

AMA time

Vectors & graphs (15 min)

A euclidean vector has magnitude & direction. (not the formal definition)

denoted with arrow: $\vec{v}$

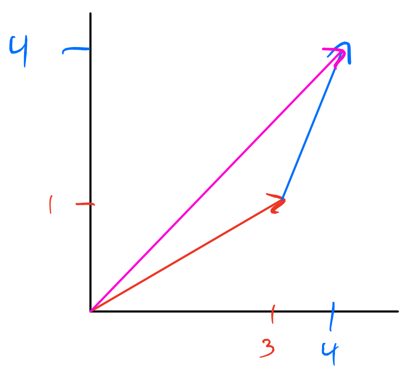


- Can write in Cartesian coordinates: (+1km, +1km) from origin
- can write w/ mag & direction: $\sqrt{2}$ km @ 45°

Vectors:
- position
- velocity
- acceleration
- electric / magnetic field
- Force

Not vectors:
- time (until relativity!)
- electric charge
- mass

Adding vectors:



$(3,1) + (1,3) = (4,4)$

Length of vector: $||\vec{v}|| = \sqrt{v_1^2 + v_2^2 + \dots + v_n^2}$

$||(4,4)|| = \sqrt{16+16} = \sqrt{32} \approx 5.6$

Scalar multiplication chgs magnitude not direction:

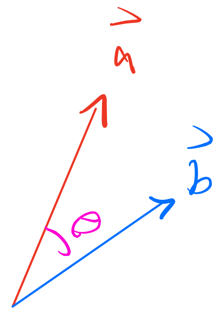
$3 \cdot (x,y,z) = (3x, 3y, 3z)$

$||(3x, 3y, 3z)|| = \sqrt{3^2x^2 + 3^2y^2 + 3^2z^2} = 3\sqrt{x^2+y^2+z^2}$

Unit vector:

$$\hat{a} = \frac{\vec{a}}{\|\vec{a}\|}$$

Dot product



$$\vec{a}\cdot\vec{b} = a_1 b_1 + a_2 b_2 + \cdots + a_n b_n$$

$$\vec{a}\cdot\vec{b} = \|\vec{a}\| \, \|\vec{b}\| \cos\Theta$$

↳ $\Theta = \cos^{-1}\left(\frac{\vec{a}\cdot\vec{b}}{\|\vec{a}\| \, \|\vec{b}\|}\right)$

$\vec{a}\cdot\vec{b} = 0 \Rightarrow$ orthogonal vectors

Zero vector: $\vec{0} = (0, 0, \dots 0)$

Zero vector is by definition orthogonal to <u>all</u> vectors

Cross product

shows up everywhere in E+M!

$$\vec{a} \times \vec{b} = \|\vec{a}\| \, \|\vec{b}\| \sin\Theta \, \hat{n}$$

$\hat{n}$ is orthogonal to $\vec{a}, \vec{b}$ given by <u>right-hand rule</u>!

Right-hand rule

(explain rule)

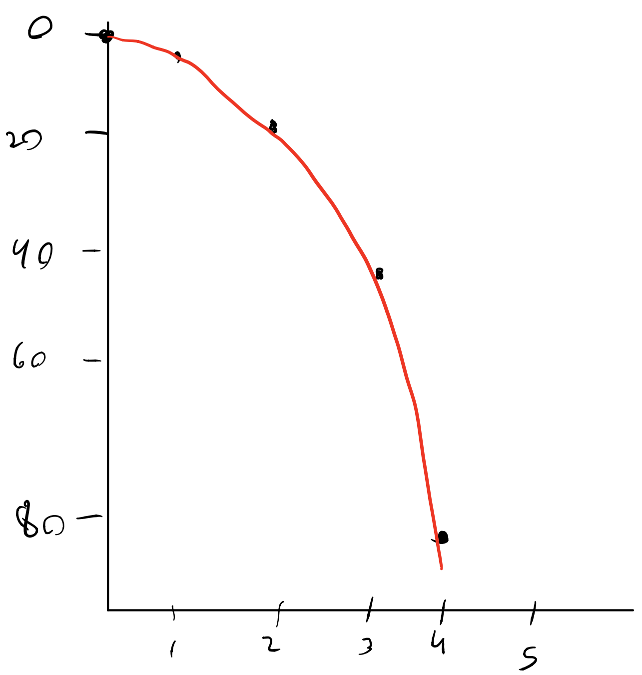
Explain decomposition into component vectors

↳ sin = vertical
cos = horizontal

Graphs:

Used to pictorially represent data.

Ex. in freefall, displacement given by $x = \frac{1}{2}gt^2$

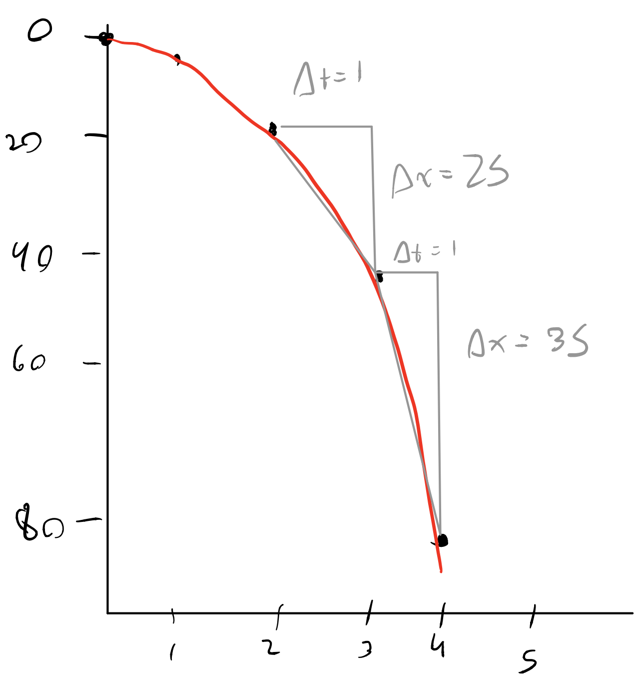


t	x
0	0
1	5
2	20
3	45
4	80

$g = 10$

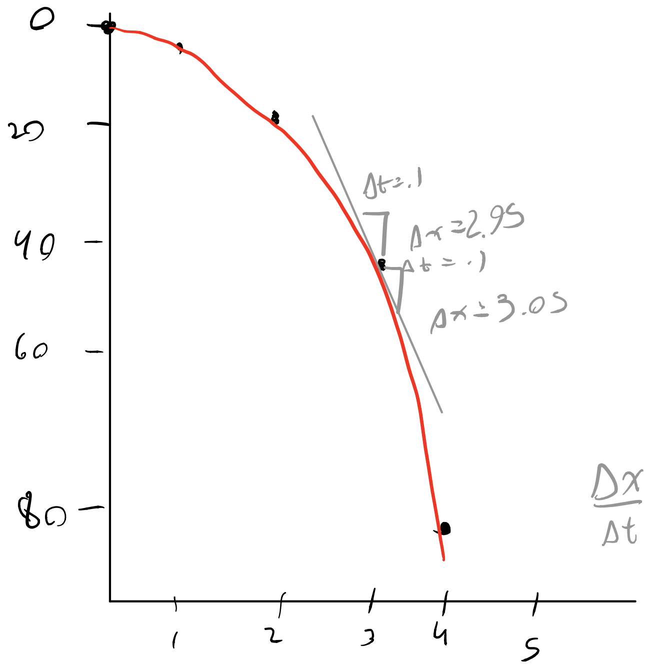
Intro to calculus (45 min)

Want to find instantaneous speed of object



$\frac{\Delta x}{\Delta t}$ is between 25 and 35

Use a smaller grid size!

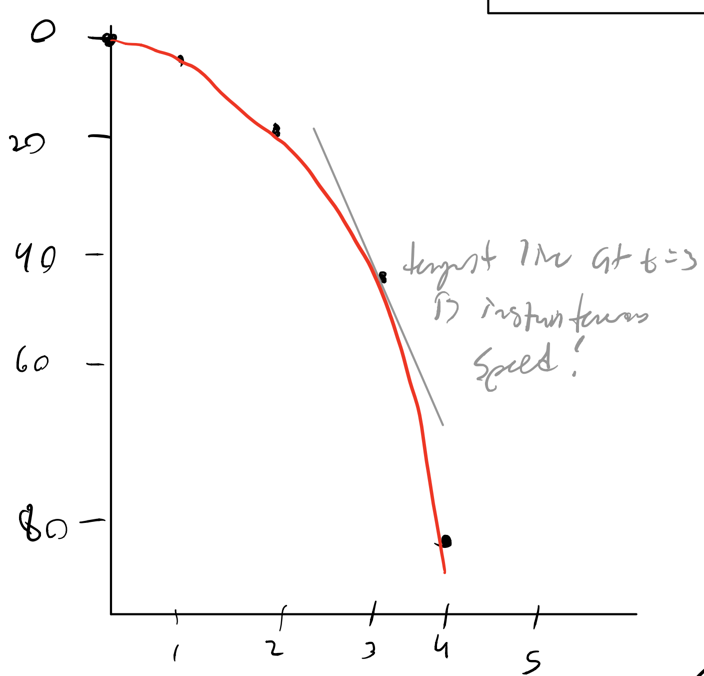


t	x
2.9	42.05
3	45
3.1	48.05

$\frac{\Delta x}{\Delta t}$ is between 29.5 and 30.5

Use a derivative

$$\boxed{\frac{df(t_0)}{dt} \equiv \lim_{\Delta t \to 0} \frac{f(t_0) + f(t_0 + \Delta t)}{\Delta t}}$$



$x = \frac{1}{2} a t^2$

$v = \frac{dx}{dt} = \frac{1}{2} \cdot 2 \cdot a t = a t$

$a = \frac{dv}{dt} = 1a$

Computing derivatives by hand isn't important for this class, but easy rules:

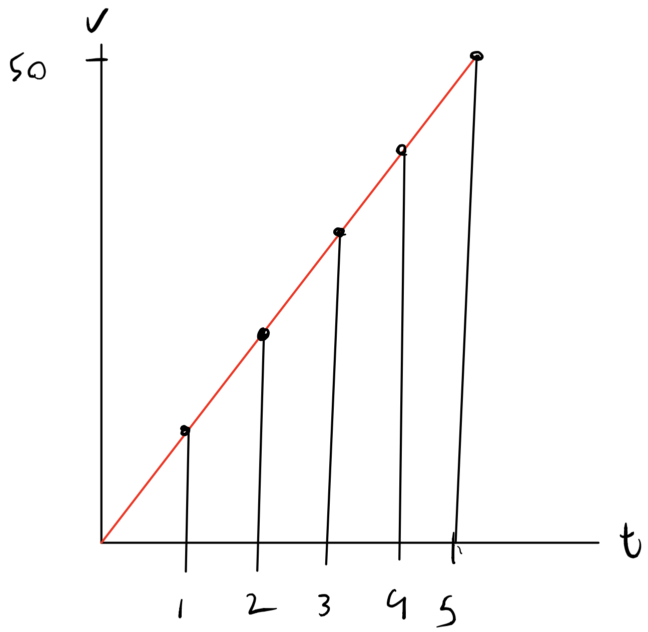
$$\left\{ \begin{array}{l} \frac{d}{dx}(c) = 0 \\ \frac{d}{dx}(kx) = k \\ \frac{d}{dx}(kx^n) = nkx^{n-1} \end{array} \right.$$

$\frac{d}{dx}(\sin(x)) = \cos(x)$

$\frac{d}{dx}(\cos(x)) = -\sin(x)$

$\frac{d}{dx}(e^x) = e^x$

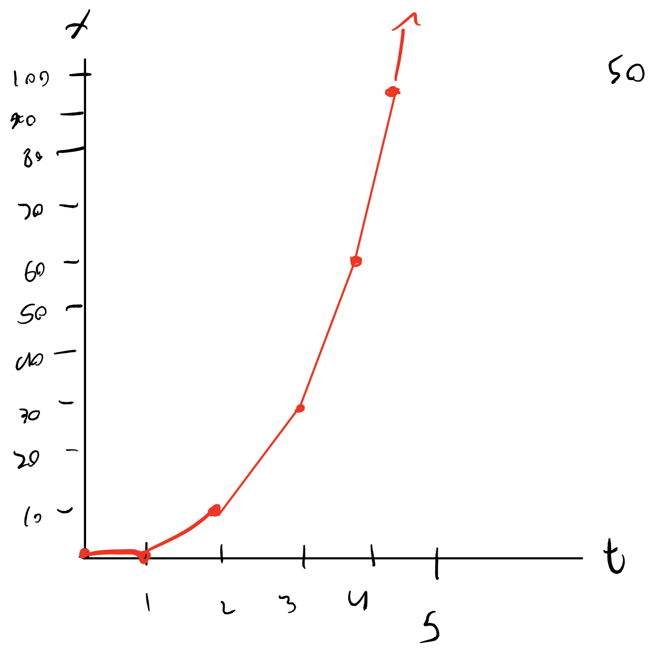
Suppose we want to know opposite problem

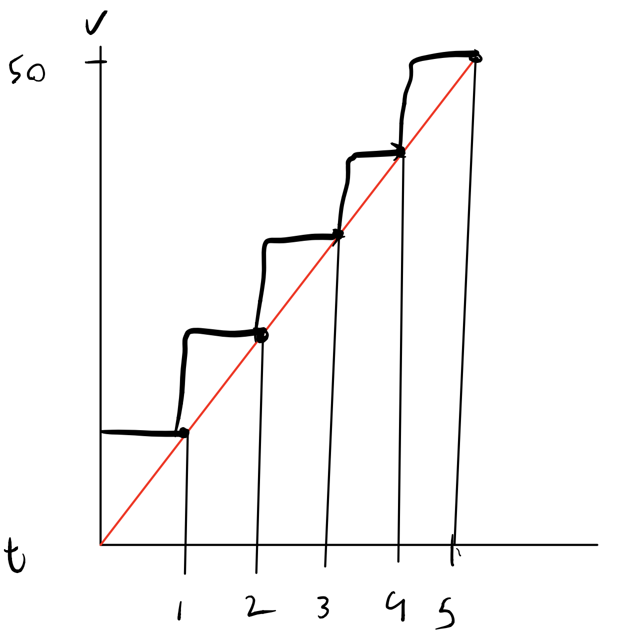


$V = at \qquad g = a = 10$

t	v
0	0
1	10
2	20
3	30
4	40
5	50

what is position?





t	$v = \frac{dx}{dt}$
0	0
1	10
2	20
3	30
4	40
5	50

$$\left.\begin{aligned} f(t) &\approx \sum_{i=0}^{n} \frac{df(t_i)}{dt} \cdot \Delta t \\ F(t) &\approx \sum_{i=0}^{n} f(t_i) \cdot \Delta t \end{aligned}\right\}$$

anti-derivatives, integral

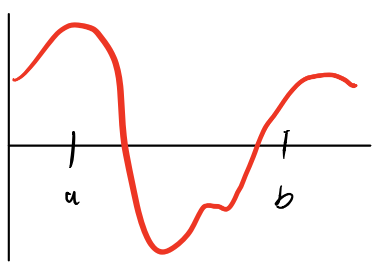
Integral:

$$\lim_{\Delta t \to 0} \sum_{i=0}^{n} f(t_i) \cdot \Delta t \equiv \int_{t_0}^{t_f} f(t)\, dt$$

limits of integration:

$$\int_a^b f(t)\, dt = F(b) - F(a)$$

Fundamental theorem of calculus:



Let f be a continuous real-valued function defined on $[a,b]$.

Let F be defined for all $t \in [a,b]$ as

$$F(x) \equiv \int_a^x f(t)\, dt.$$

Then F is continuous & differentiable on $[a,b]$ and

$$\frac{dF(x)}{dx} = f(x)$$