

Measuring Things

Test an equation:

$$F = ma$$

!!

F	a	δF	δa
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—

(t)

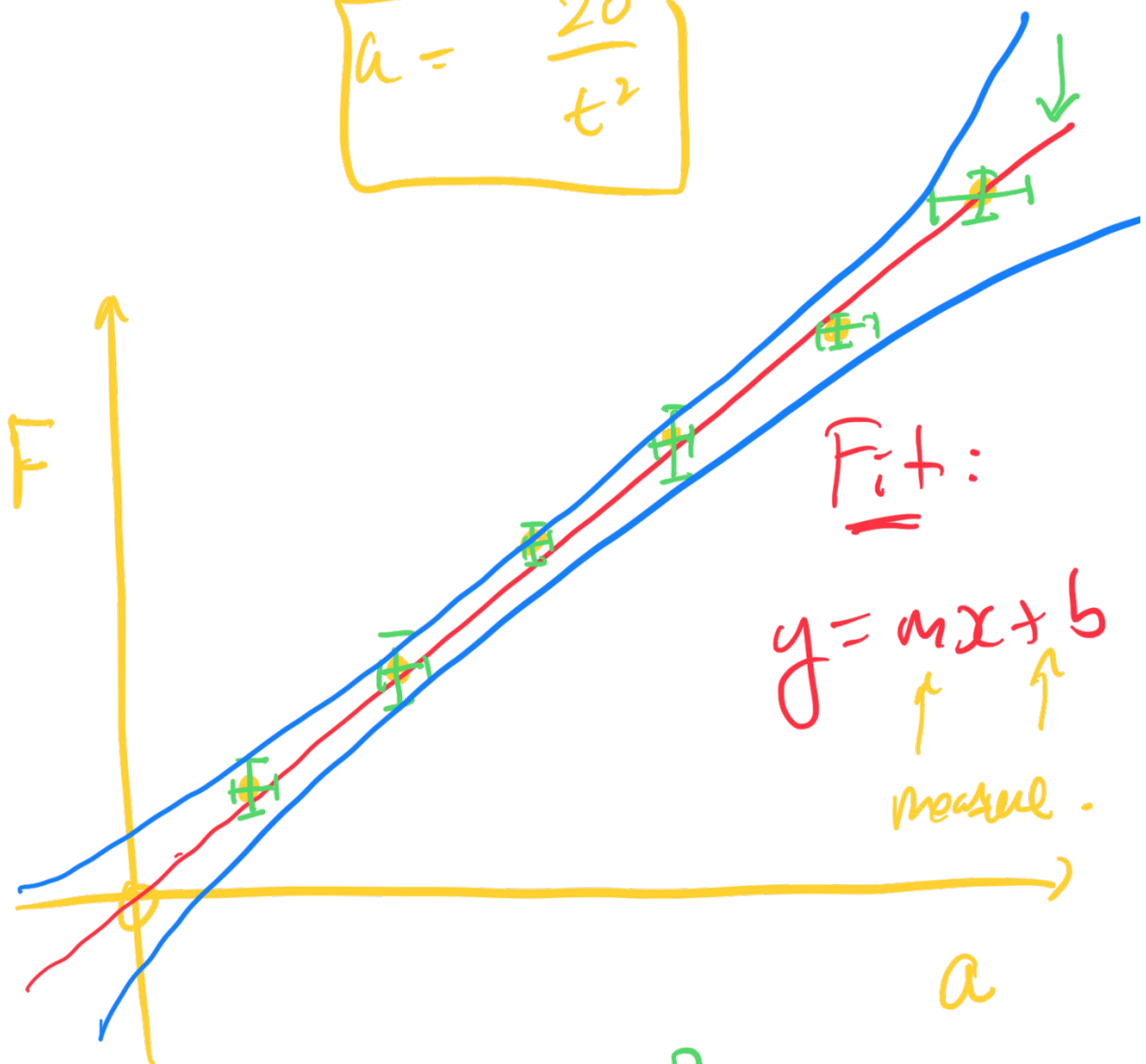




$$\Delta x = \cancel{v_i t^0} + \frac{1}{2} a t^2$$

$$10 = \frac{1}{2} a t^2$$

$$a = \frac{20}{t^2}$$



Is it linear?

② What is the slope?

$$\hat{F} = \boxed{m} a$$
$$y = \boxed{m} x + \boxed{b}$$

③ Is $b = 0$?

Complications:

A) Every quantity that we measure has an uncertainty!!!!

① estimate ... multiple trials.

$$\hat{F} = 100 \text{ N} \pm \dots$$

$$a = \begin{matrix} 3.0 \\ 3.02 \\ 3.1 \\ 2.98 \\ \vdots \end{matrix} \pm .02$$

(2) Instrumental Uncertainty

Voltage.

2.06	V
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↑

$$\pm .005 \text{ V}$$

B) Errors in the Fit
(uncertainties)

$$y = mx + b$$

$m \pm \delta m$!! o.o
$b \pm \delta b$	

← CAN'T DO

"trendline"

THIS IN
EXCEL!!

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

↑
10 kg

$$\text{Slope} = (10.0 \pm 0.2) \text{ kg.}$$

😊

$b = 0.2 \pm 0.3$

consistent with
zero!!

$$= (9.4 \pm .2) \text{ kg}$$

😞

"fairly good agreement"
??
...

Coulomb's Law

Newton \rightarrow Invert Calculus.



Test? \rightarrow

$$|\vec{F}_E| = k_e \frac{|Q_1| |Q_2|}{R^2}$$

Symmetry

gravity

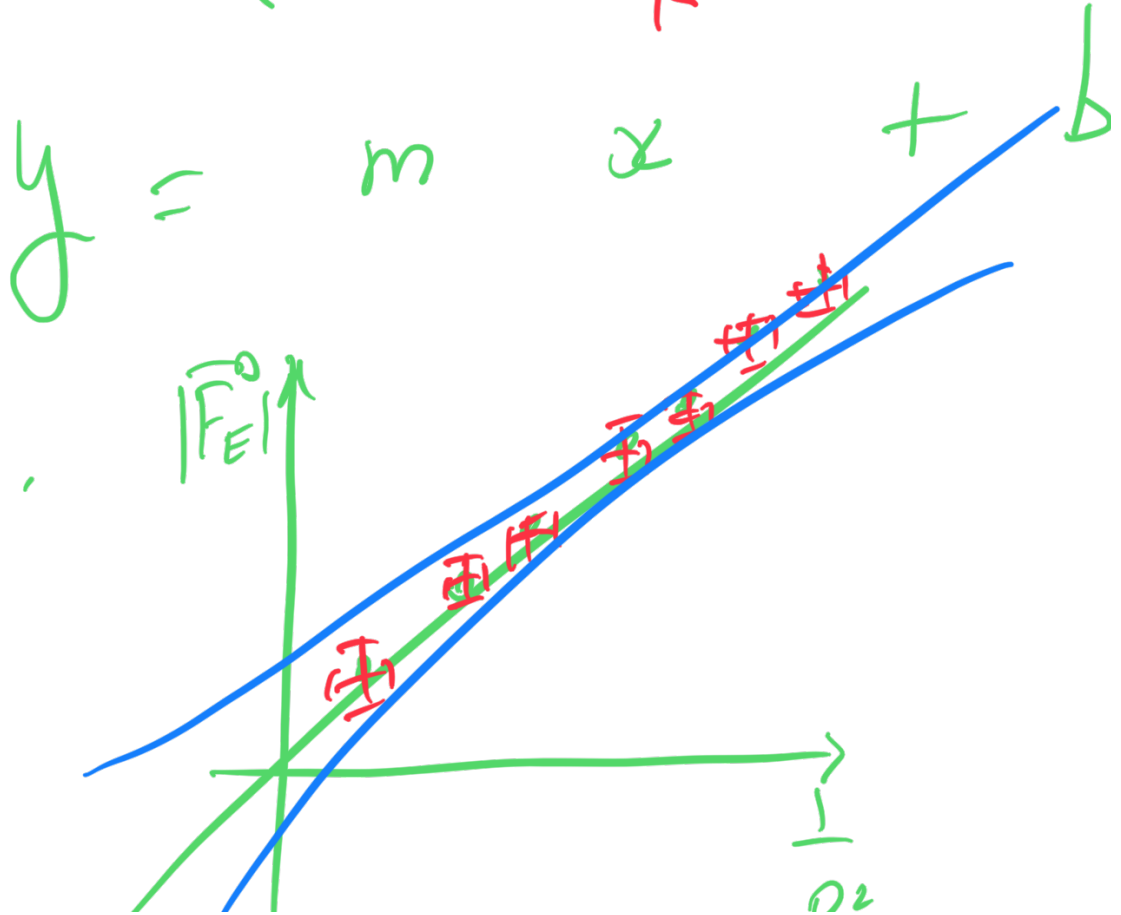
$$|\vec{F}_g| = G \frac{m_1 m_2}{R^2}$$





$$|\vec{F}_E| = k_e \frac{|Q_1||Q_2|}{R^2}$$

$$|\vec{F}_E| = (k_e |Q_1||Q_2|) \frac{1}{R^2}$$



$$b = 0, \quad m = k_e |Q|^2$$

$$b \pm \delta b$$

$$m \pm \delta m$$

Measuring Force is insurably hard

Torsion Balance / Pendulum.

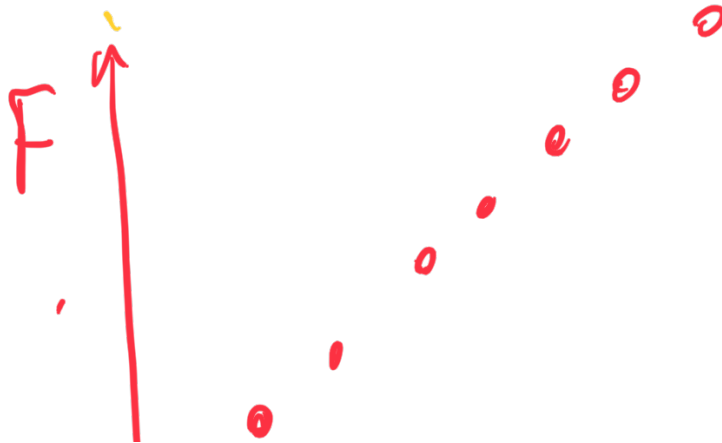


Connection between F vs. θ
How?
measure.

Calibration

$$F = C \theta$$

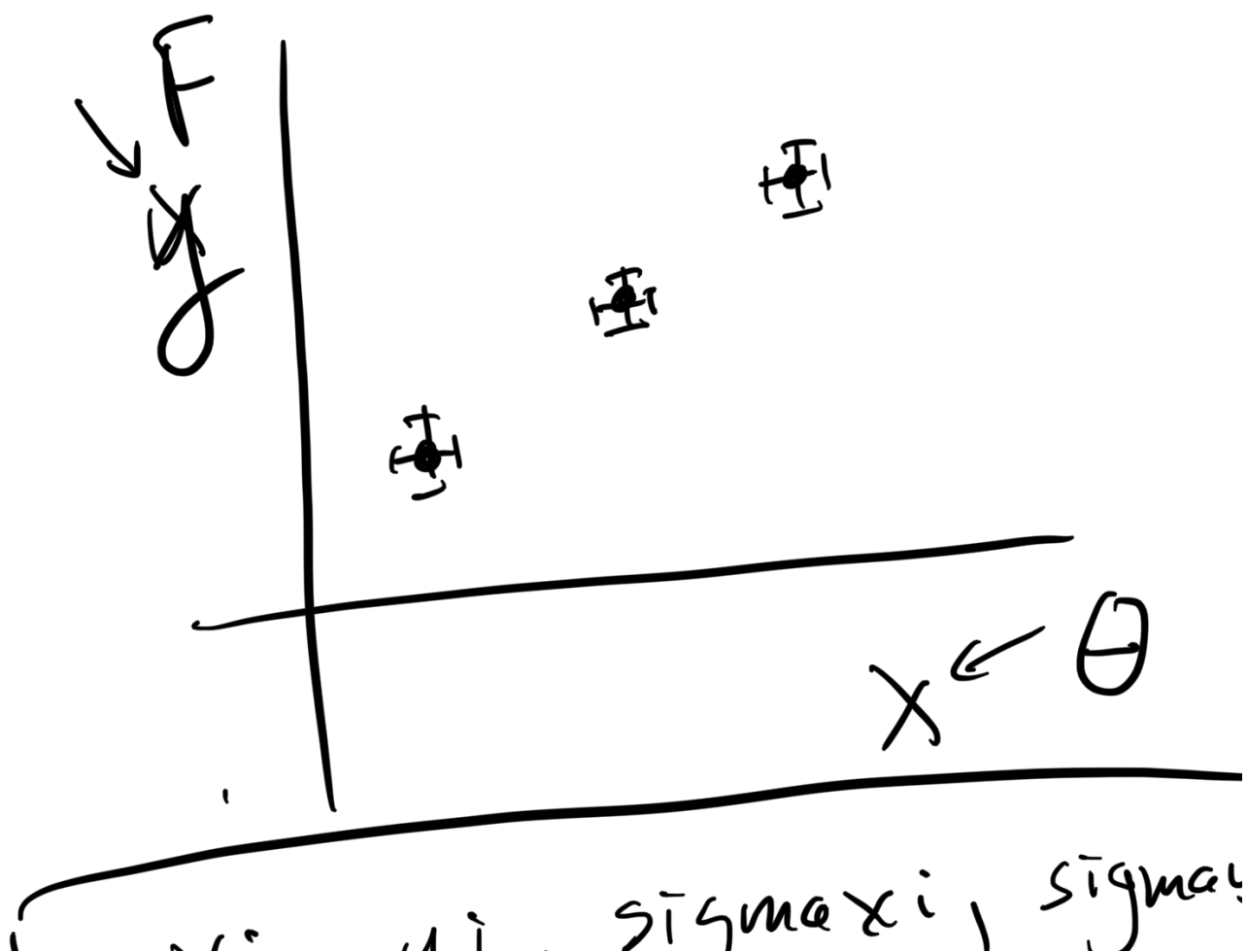
determine





Stage 1: Raw Data \rightarrow Process

Stage 2: Filter.



x_i, y_i, \dots