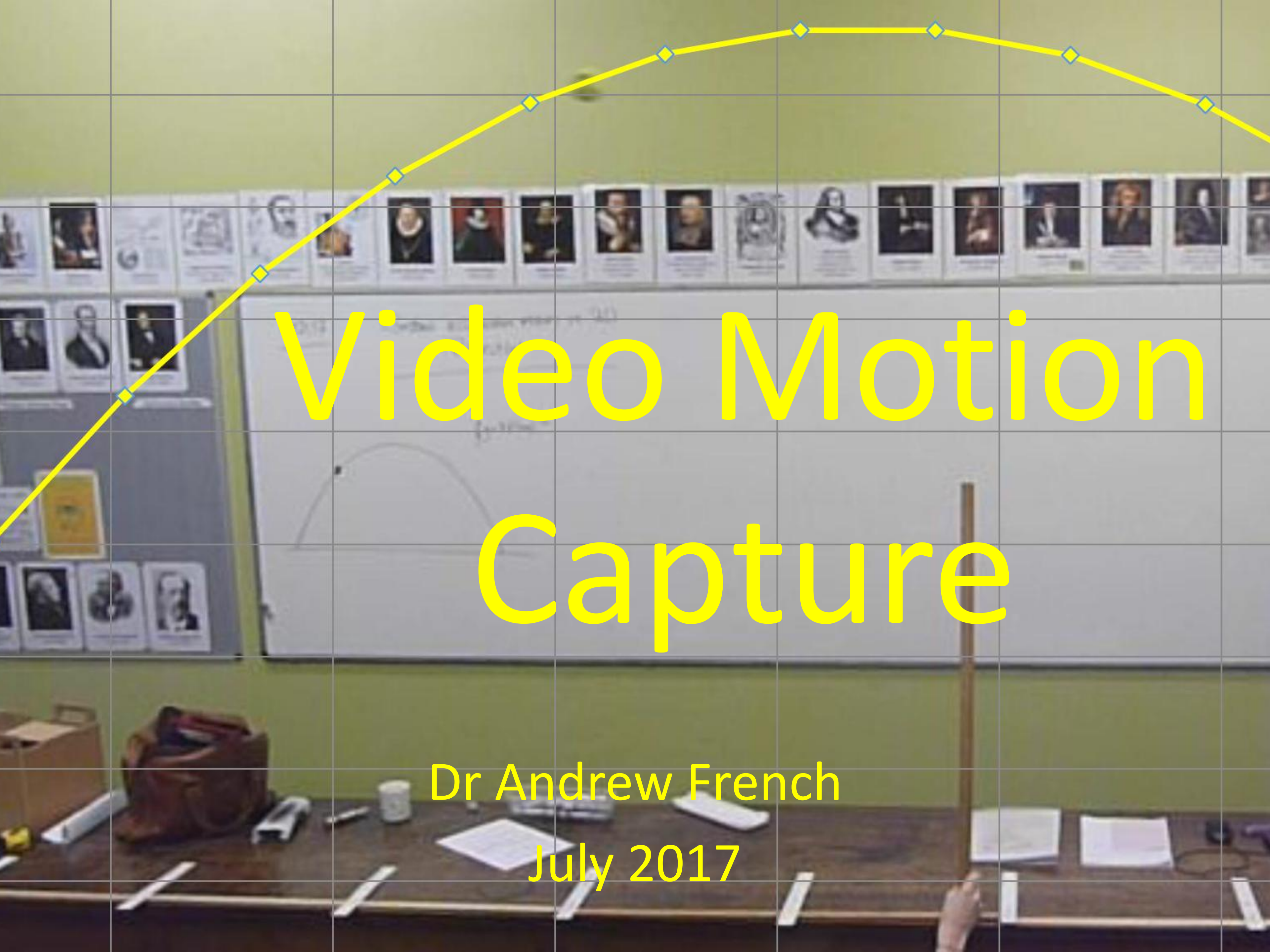

Video Motion Capture

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This experiment is about the study of motion, or **kinematics**.
Physics uses *numbers* to quantify aspects of motion i.e.

The **position**, **velocity** and **acceleration** of an object vs **time**.

Kinematics of Usain Bolt

To keep things simple we will look at the **motion of a tennis ball**.
We will *ignore*:

- Rotation of the ball
- Effects of air resistance (i.e. the ball colliding with air molecules)

EXPERIMENT 1 Drop ball from a fixed height (e.g. 2m)
EXPERIMENT 2 Throw ball and record its *parabolic* trajectory

What will we do?

We will use a **30 frames per second video camera** to record the **position** of the tennis ball vs **time**. `Quicktime` will be used to step through the video frames. Three frame clicks correspond to 0.1 s.

We'll then do some **analysis** in `Excel`.
- Plot position vs time using a **scatter graph**
- Compare our data to a **mathematical model** of the motion

Extension
What happens when the ball bounces?

Experiment 1 – Ball drop

The Scientific Method

recap!

2 **Propose a theory**, involving things that can be measured

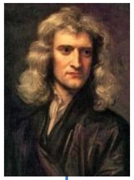
$$x = \frac{1}{2} g t^2$$

Distance fallen

Acceleration (i.e. the rate at which speed increases)

Time

On Earth!

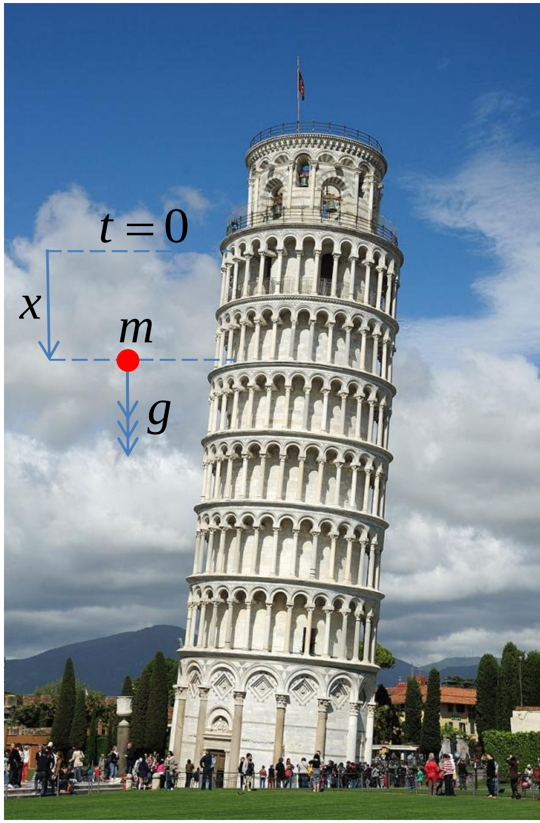


$$\boxed{g = 9.81\text{ms}^{-2}}$$

3 **Do an experiment**

Is there a match between theory and measured results?

Is the experiment repeatable?



Galileo Galilei
1564-1642

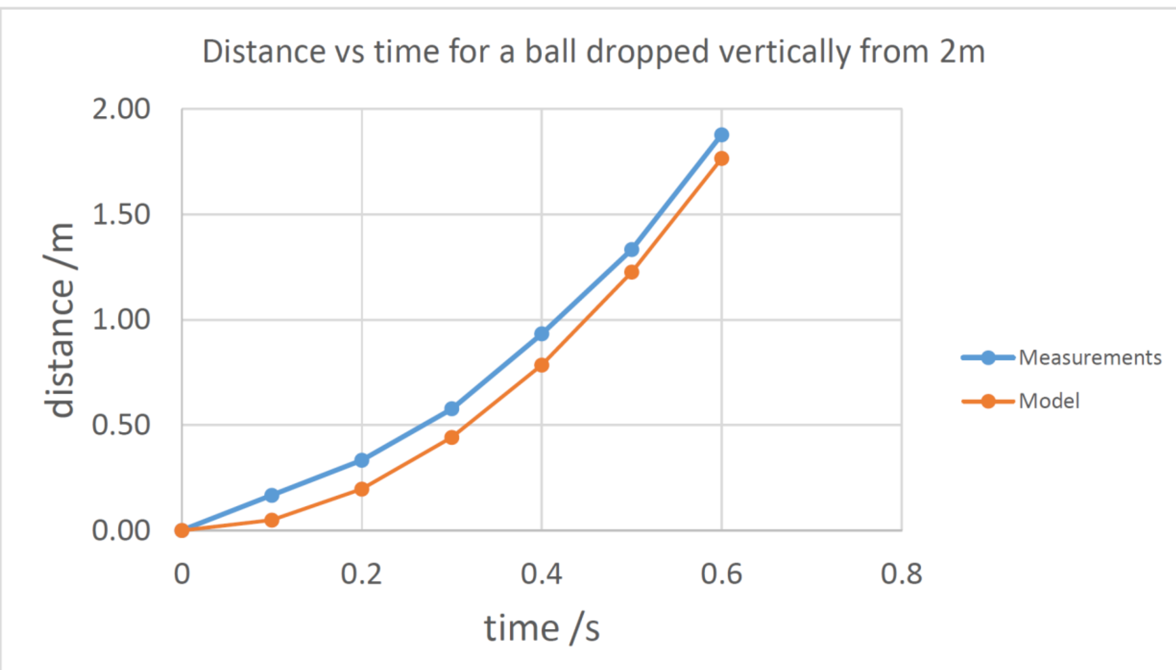
1 **Make some observations**

"Falling objects seem to accelerate at the same rate... Independent of how massive they are!"

If we ignore air resistance!

4 **Write up your findings** and allow your peers to review it

# clicks	time /s	Screen drop distance /cm	Actual drop distance /m	0.5*g*t^2
0	0	0	0.00	0
3	0.1	1.5	0.17	0.04905
6	0.2	3	0.33	0.1962
9	0.3	5.2	0.58	0.44145
12	0.4	8.4	0.93	0.7848
15	0.5	12	1.33	1.22625
18	0.6	16.9	1.88	1.7658



g
9.81

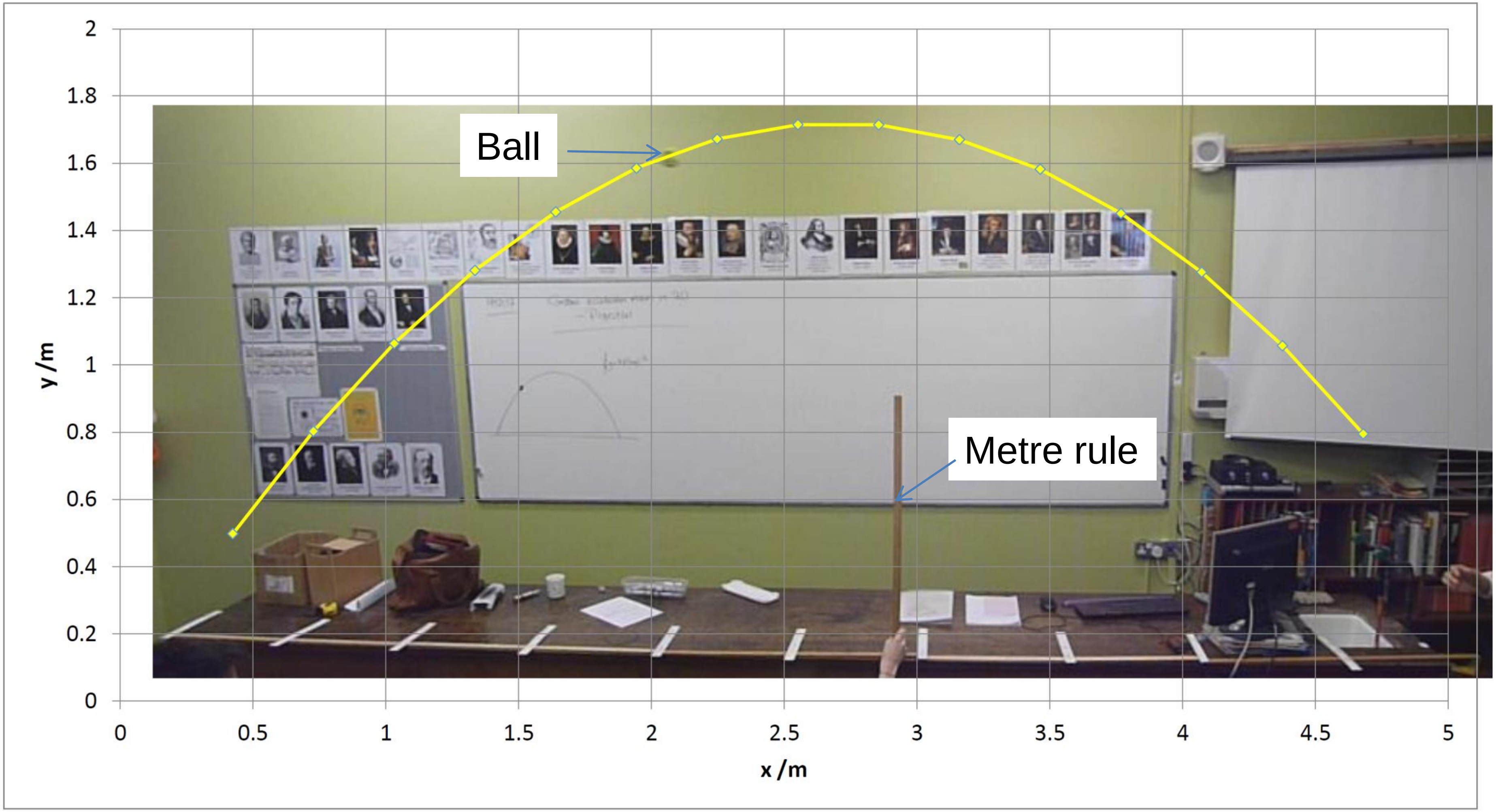
$$x = \frac{1}{2} g t^2$$

Distance fallen

Time

Acceleration (i.e. the rate at which speed increases)

Experiment 2 – Ball throw

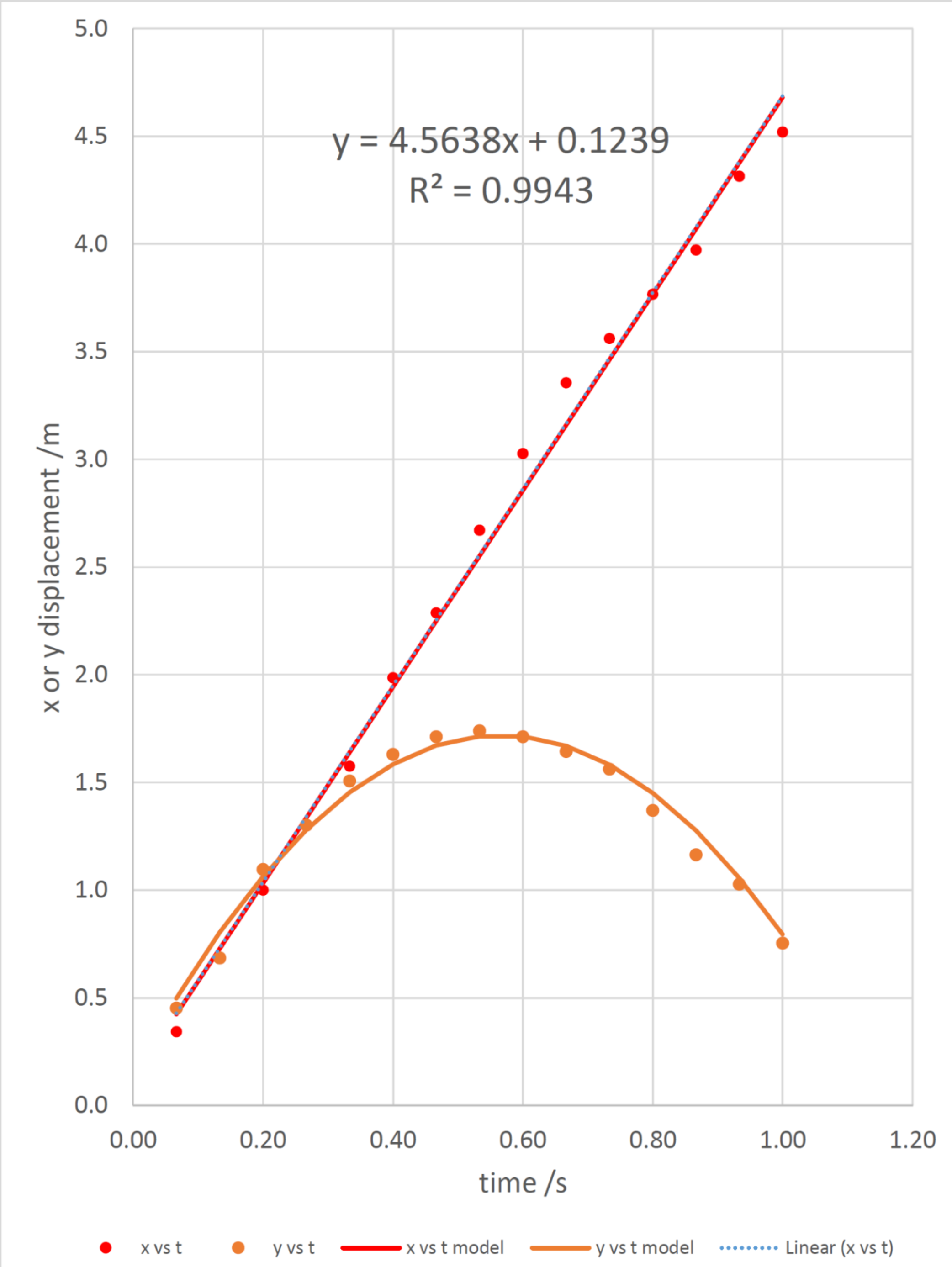


Throw a ball over a 5m distance, with a metre rule clearly visible. Video using a digital camera at 30 frames per second. Open the resulting movie file in **Quicktime** and manually skip through the frames.
Use a ruler to record the ball position relative to the computer screen and then calibrate to metres using the metre stick. Analyse in Excel, and overlay a screenshot with the x vs y parabola as shown above.

	screen			reality		XUVAT model	
click #	t /s	x /cm	y/cm	x /m	y /m	x /m	y /m
2	0.07	2.5	3.3	0.3	0.5	0.42	0.5
4	0.13	5.0	5.0	0.7	0.7	0.73	0.8
6	0.20	7.3	8.0	1.0	1.1	1.03	1.06
8	0.27	9.5	9.5	1.3	1.3	1.34	1.28
10	0.33	11.5	11.0	1.6	1.5	1.64	1.46
12	0.40	14.5	11.9	2.0	1.6	1.94	1.59
14	0.47	16.7	12.5	2.3	1.7	2.25	1.67
16	0.53	19.5	12.7	2.7	1.7	2.55	1.71
18	0.60	22.1	12.5	3.0	1.7	2.86	1.71
20	0.67	24.5	12.0	3.4	1.6	3.16	1.67
22	0.73	26.0	11.4	3.6	1.6	3.46	1.58
24	0.80	27.5	10.0	3.8	1.4	3.77	1.45
26	0.87	29.0	8.5	4.0	1.2	4.07	1.28
28	0.93	31.5	7.5	4.3	1.0	4.38	1.06
30	1.00	33.0	5.5	4.5	0.8	4.68	0.8

30FPS video recording

1 click = 1/30 s



Displacement vs time equations (ignore drag, only include weight)

$$x = x_0 + u_x t$$

$$y = y_0 + u_y t - \tfrac{1}{2} g t^2$$

Initial velocities /ms^-1

ux	**4.56**
uy	**5.55**

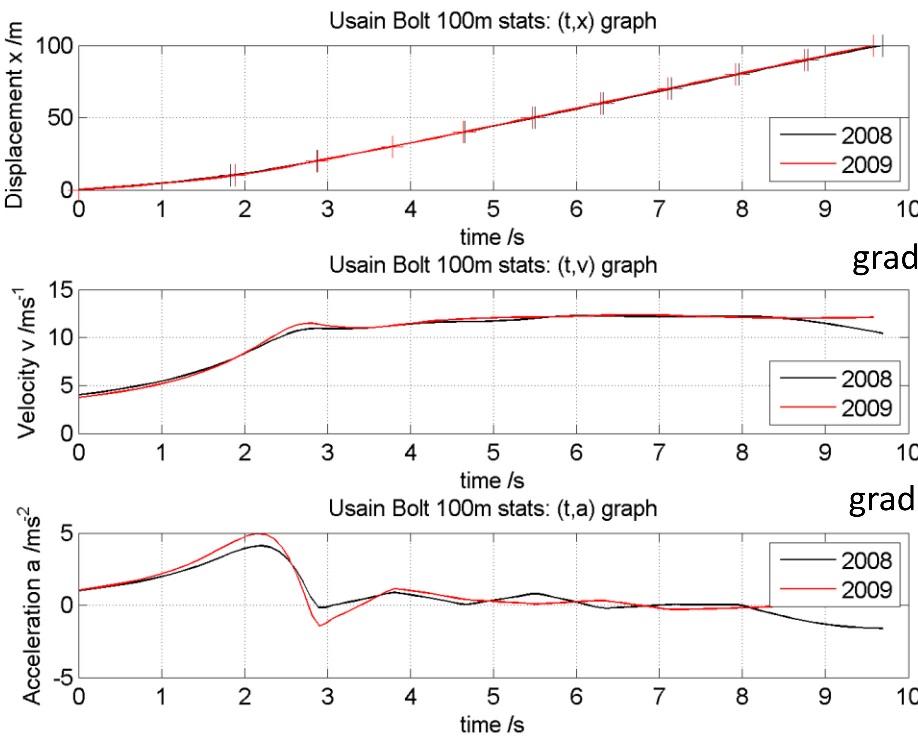
launch speed / ms^-1
7.183

g	**9.81**	gravitational acceleration
x0	**0.12**	initial x value
y0	**0.15**	initial y value

Find x velocity using a line of best fit to x vs t data.

Perform a similar process using $y + \tfrac{1}{2} g t^2$ vs time to find the initial y component (vertical) velocity.

Relationship between displacement, velocity and acceleration



gradient $\frac{dx}{dt}$

gradient $\frac{dv}{dt}$

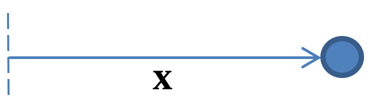
Useful speed conversions:

$1\ ms^{-1}$ = 2.24 miles per hour

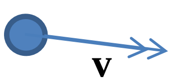
$1\ ms^{-1}$ = 3.6 km per hour

$$t\,/\,\text{min} = 60 \times \frac{x\,/\,\text{miles}}{v\,/\,\text{mph}}$$

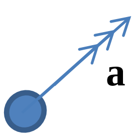
Speed in mph	Time in minutes per 10 miles
10	60
20	30
30	20
40	15
50	12
60	10
70	8.57



Displacement is the vector between a fixed origin and the point of interest. If an object is moving, the displacement will vary with time t



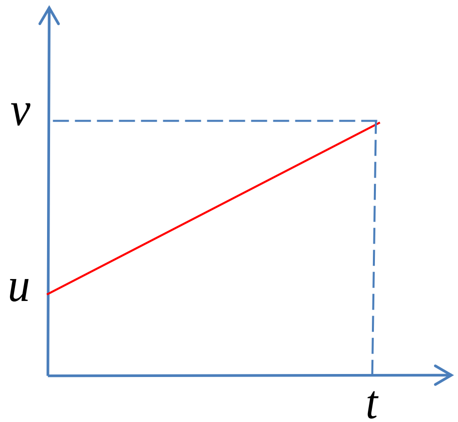
Velocity is the *rate of change of displacement*. If velocity is in the same direction as displacement,
it is the gradient of a (t,x) graph.



Acceleration is the *rate of change of velocity*. If acceleration is in the same direction as velocity, it is the gradient of a (t,v) graph.

Constant acceleration motion

It is almost *always* a good idea to start with a (t,v) graph.
Let velocity increase at the same rate a from u to v in t seconds.



The acceleration is the gradient: $a = \dfrac{v-u}{t} \quad \therefore \quad \boxed{v = u + at}$

The area under the graph is the displacement.
Since this a trapezium shape: $\boxed{x = \frac{1}{2}(u+v)t}$

We can work out other useful relationships for constant acceleration motion

$$x = \tfrac{1}{2}(u + u + at)t$$

$$\boxed{x = ut + \tfrac{1}{2}at^2}$$

$$x = ut + \tfrac{1}{2}at^2$$

$$2ax = 2uat + a^2t^2$$

$$v^2 = (u+at)^2 = u^2 + 2uat + a^2t^2$$

$$\therefore \boxed{v^2 = u^2 + 2ax}$$