DEVIL PHYSICS
BADDEST CLASS ON CAMPUS
IB PHYSICS

LESSON 2-1C

PROJECTILE MOTION

FLUID RESISTANCE

Introduction Videos

- Projectile Motion 1
- Useful Applications of Projectile Motion

Essential Idea:

- Motion may be described and analyzed by the use of graphs and equations.

Nature Of Science:

- Observations: The ideas of motion are fundamental to many areas of physics, providing a link to the consideration of forces and their implication. The kinematic equations for uniform acceleration were developed through careful observations of the natural world.

International-Mindedness:

- International cooperation is needed for tracking shipping, land-based transport, aircraft and objects in space.

Theory Of Knowledge:

- The independence of horizontal and vertical motion in projectile motion seems to be counter-intuitive.
- How do scientists work around their intuitions?
- How do scientists make use of their intuitions?

Understandings:

- Projectile motion
- Fluid resistance and terminal speed

Applications And Skills:

- Analyzing projectile motion, including the resolution of vertical and horizontal components of acceleration, velocity and displacement.
- Qualitatively describing the effect of fluid resistance on falling objects or projectiles, including reaching terminal speed.

Guidance:

- Calculations will be restricted to those neglecting air resistance.
- Projectile motion will only involve problems using a constant value of g close to the surface of the Earth.
- The equation of the path of a projectile will not be required.

Data Booklet Reference:

$$v = u + at$$

$$s = ut + 1/2\, at^2$$

$$v^2 = u^2 + 2as$$

$$s = \frac{(v + u)t}{2}$$

Utilization:

- Diving, parachuting and similar activities where fluid resistance affects.
- The accurate use of ballistics requires careful analysis.
- Quadratic functions (see Mathematics HL sub-topic 2.6; Mathematics SL sub-topic 2.4; Mathematical studies SL sub-topic 6.3).
- The kinematic equations are treated in calculus form in Mathematics HL sub-topic 6.6 and Mathematics SL sub-topic 6.6.

Aims:

- Aim 2: much of the development of classical physics has been built on the advances in kinematics

Aims:

- Aim 6: experiments, including use of data logging, could include (but are not limited to): determination of g, estimating speed using travel timetables, analyzing projectile motion, and investigating motion through a fluid

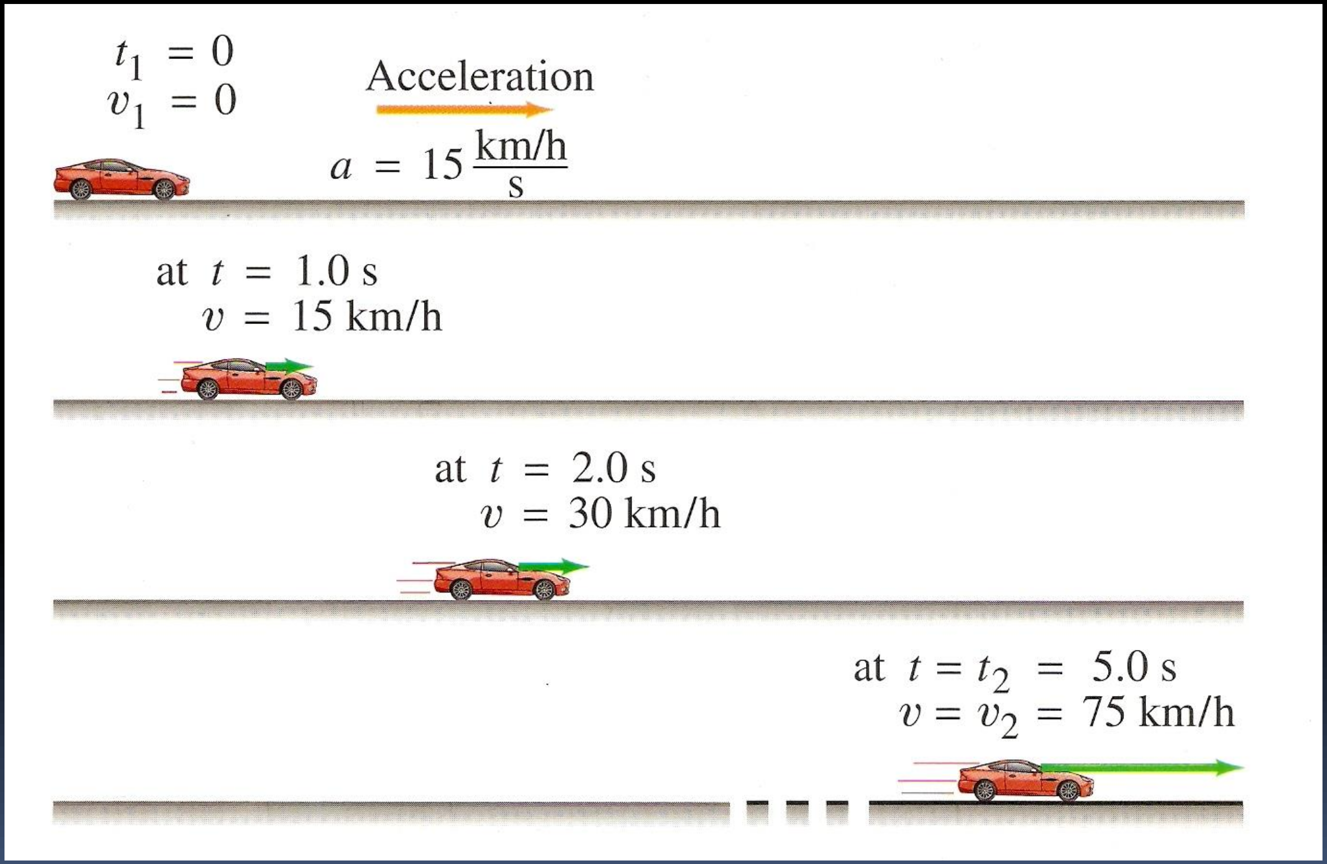
Aims:

- Aim 7: technology has allowed for more accurate and precise measurements of motion, including video analysis of real-life projectiles and modeling/simulations of terminal velocity

One Dimensional Motion

WHERE WE'VE BEEN

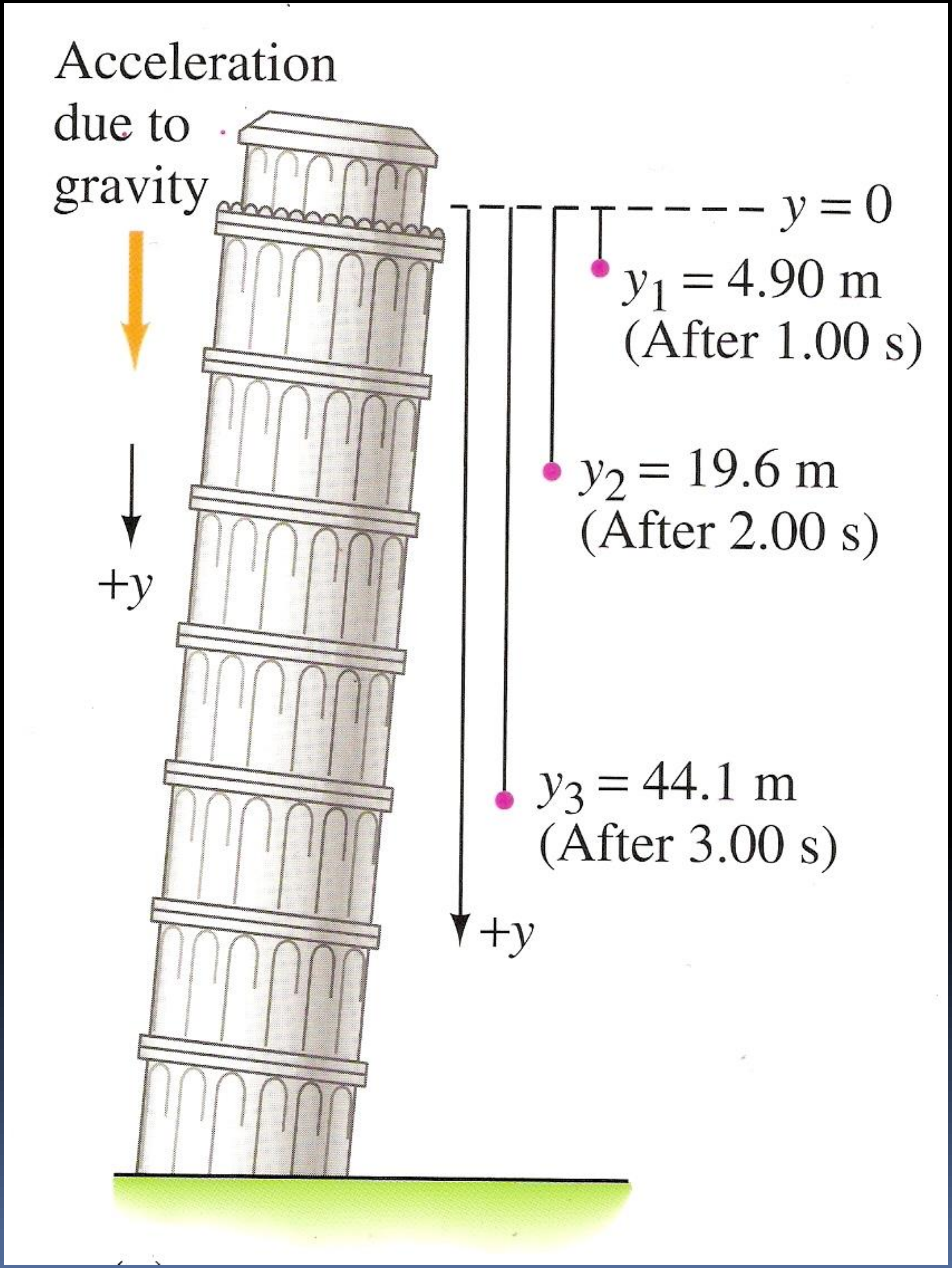
Horizontal Motion



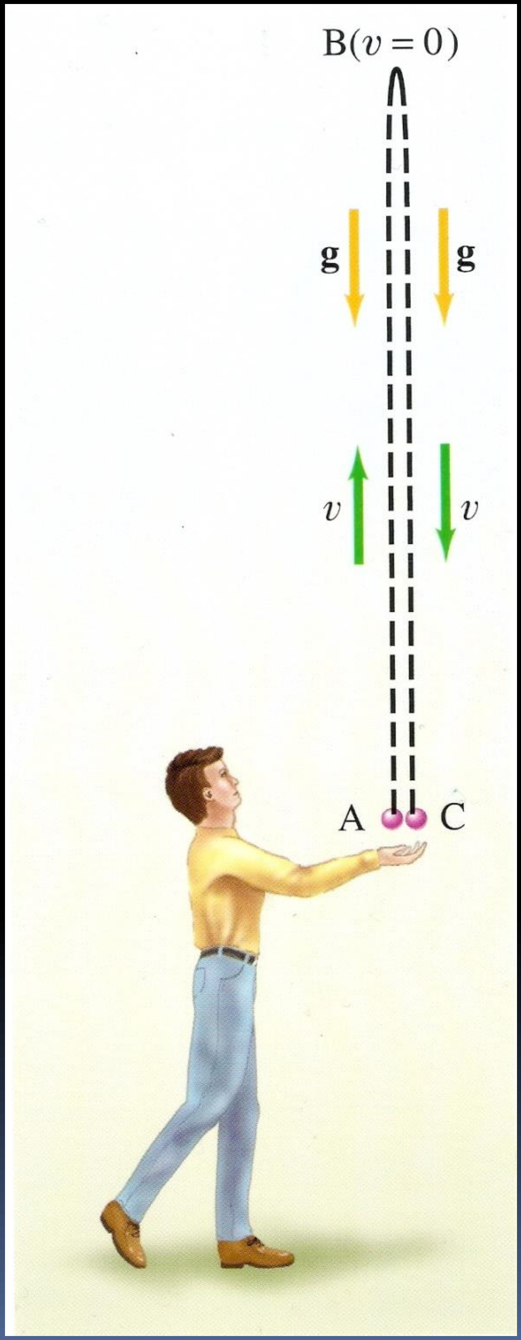
Kinematic Equations for Horizontal Motion

$v = v_0 + at$	$[a = \text{constant}]$
$x = x_0 + v_0 t + \frac{1}{2}at^2$	$[a = \text{constant}]$
$v^2 = v_0^2 + 2a(x - x_0)$	$[a = \text{constant}]$
$\overline{v} = \frac{v + v_0}{2}.$	$[a = \text{constant}]$

Vertical Motion – Drop Problems



Vertical Motion with Vertical Velocity



Kinematic Equations

Horizontal

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + 1/2\, a_x t^2$$

$$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$$

Vertical

$$v_y = v_{y0} + a_y t$$

$$y = y_0 + v_{y0} t + 1/2\, a_y t^2$$

$$v_y^2 = v_{y0}^2 + 2a_y (y - y_0)$$

Kinematic Equations

- IB Style

$$v = u + at$$

$$s = ut + 1/2\, at^2$$

$$v^2 = u^2 + 2as$$

$$s = \frac{(v + u)t}{2}$$

Vectors

WHERE WE'VE BEEN

Vectors and Scalars

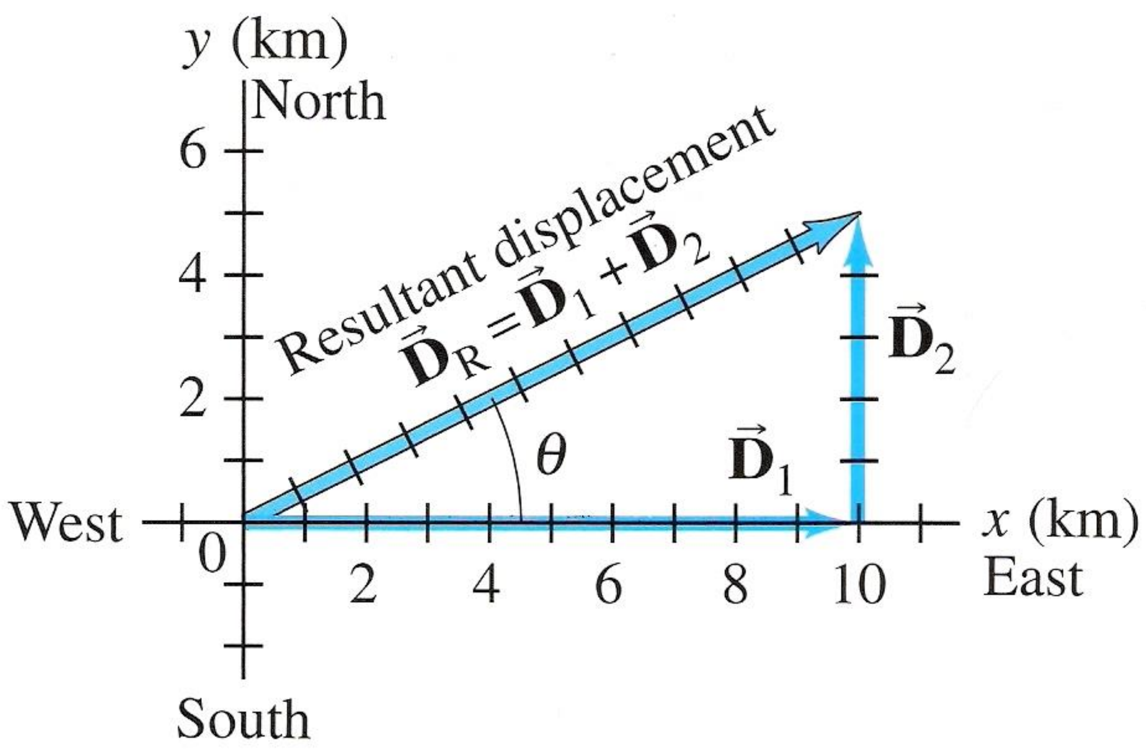
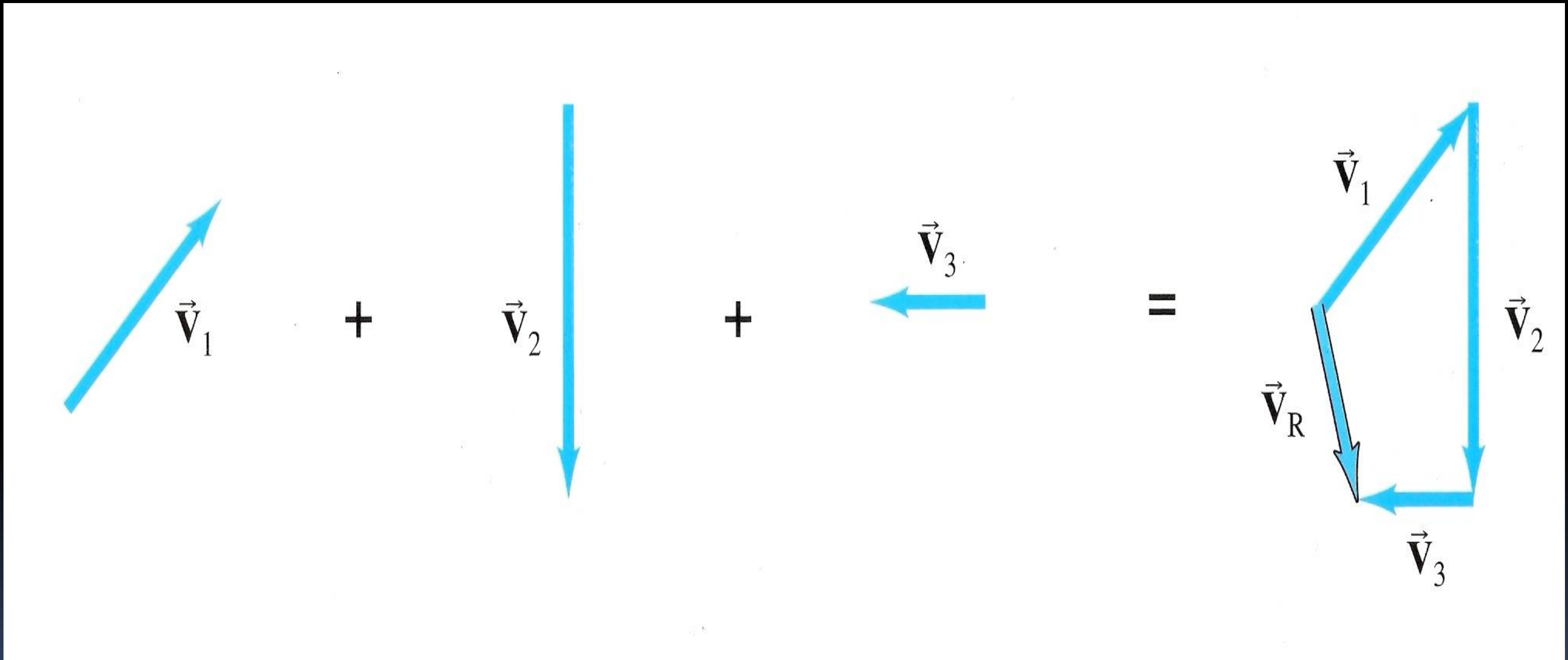
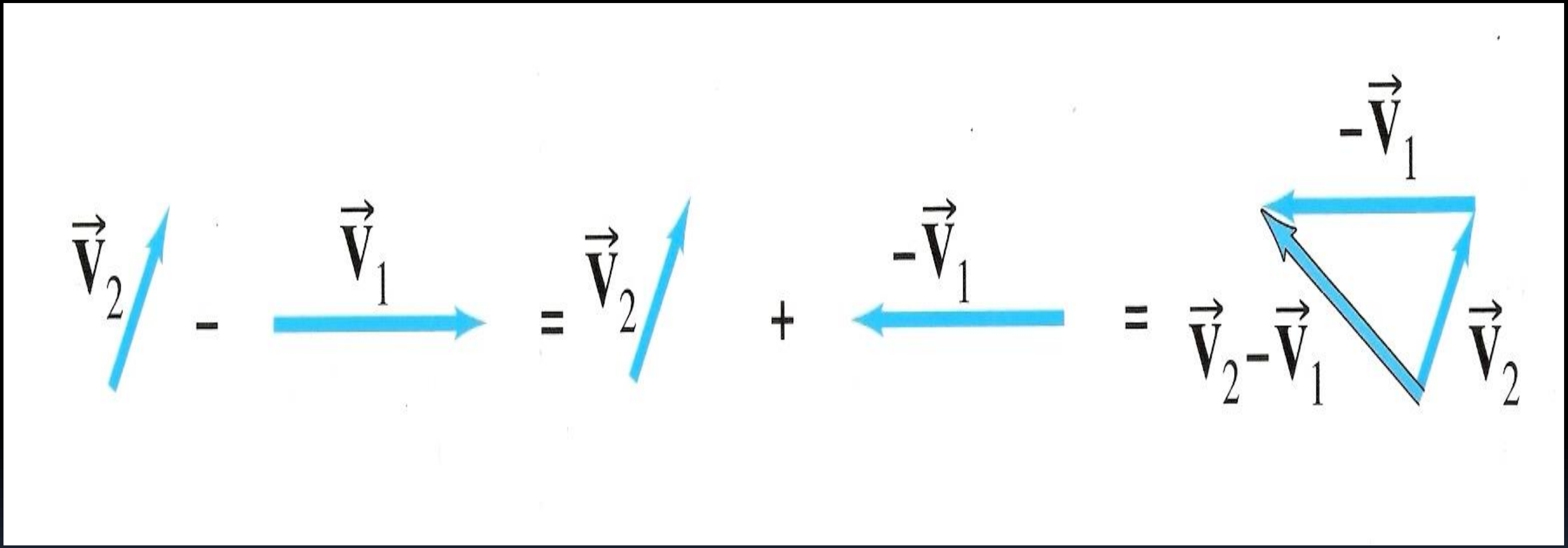


Figure 3-3 **A person walks 10.0 km east and then 5.0 km north**

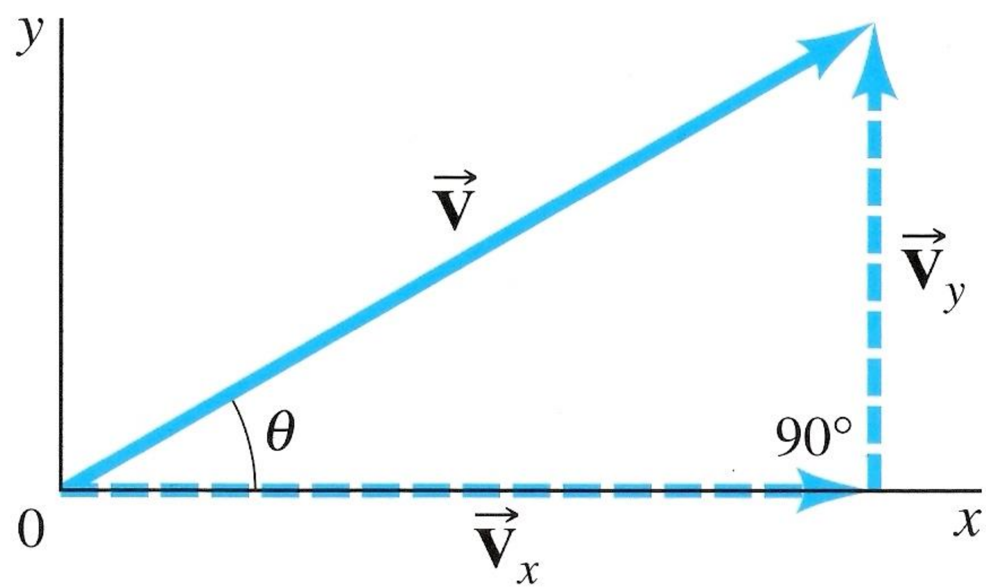
Vector Addition - Graphically



Vector Subtraction - Graphically



Breaking Vectors Down Into Components



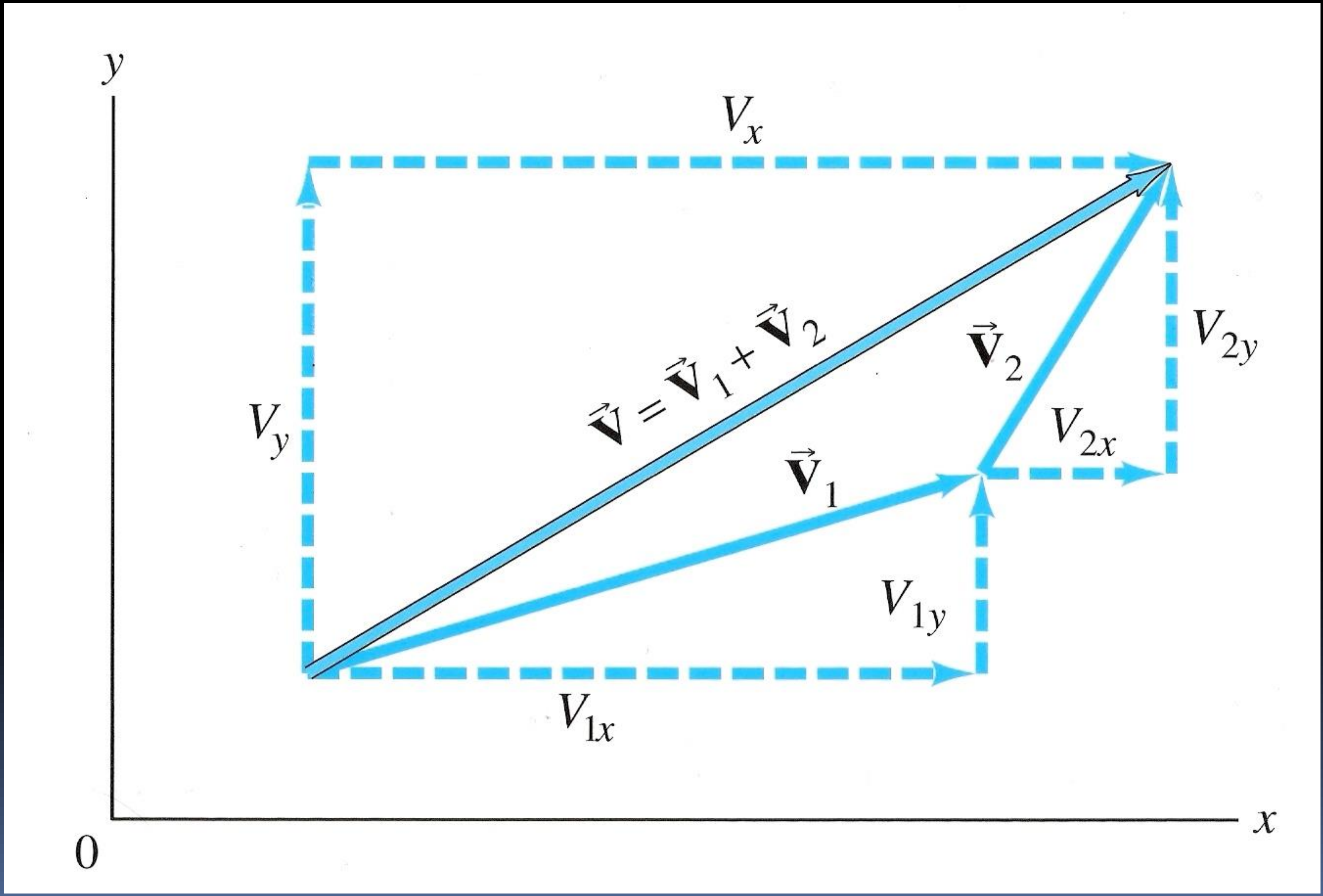
$$\sin\theta = \frac{V_y}{V}$$

$$\cos\theta = \frac{V_x}{V}$$

$$\tan\theta = \frac{V_y}{V_x}$$

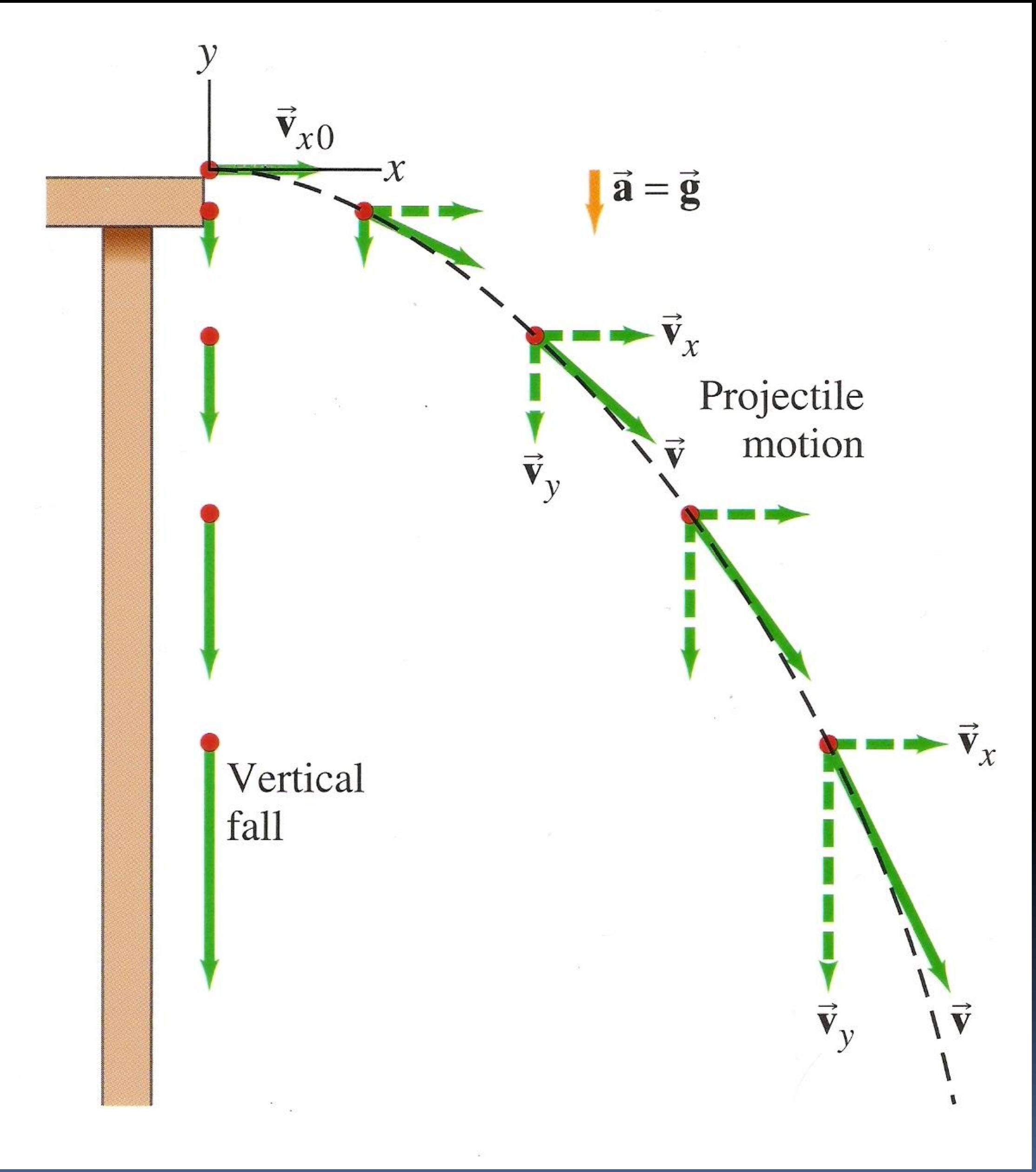
$$V^2 = V_x^2 + V_y^2$$

Adding Vectors Using Components

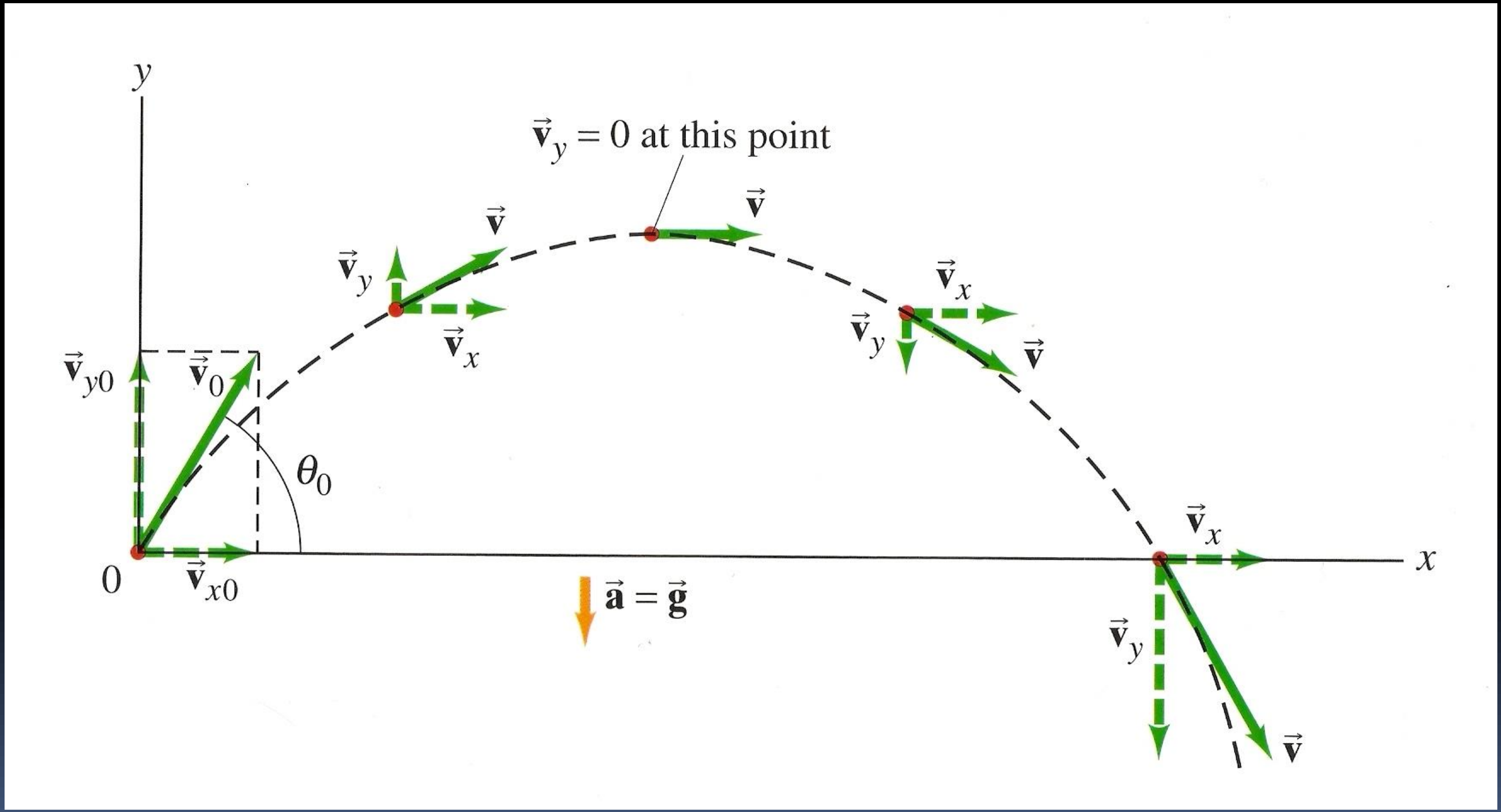


PUTTING IT ALL TOGETHER

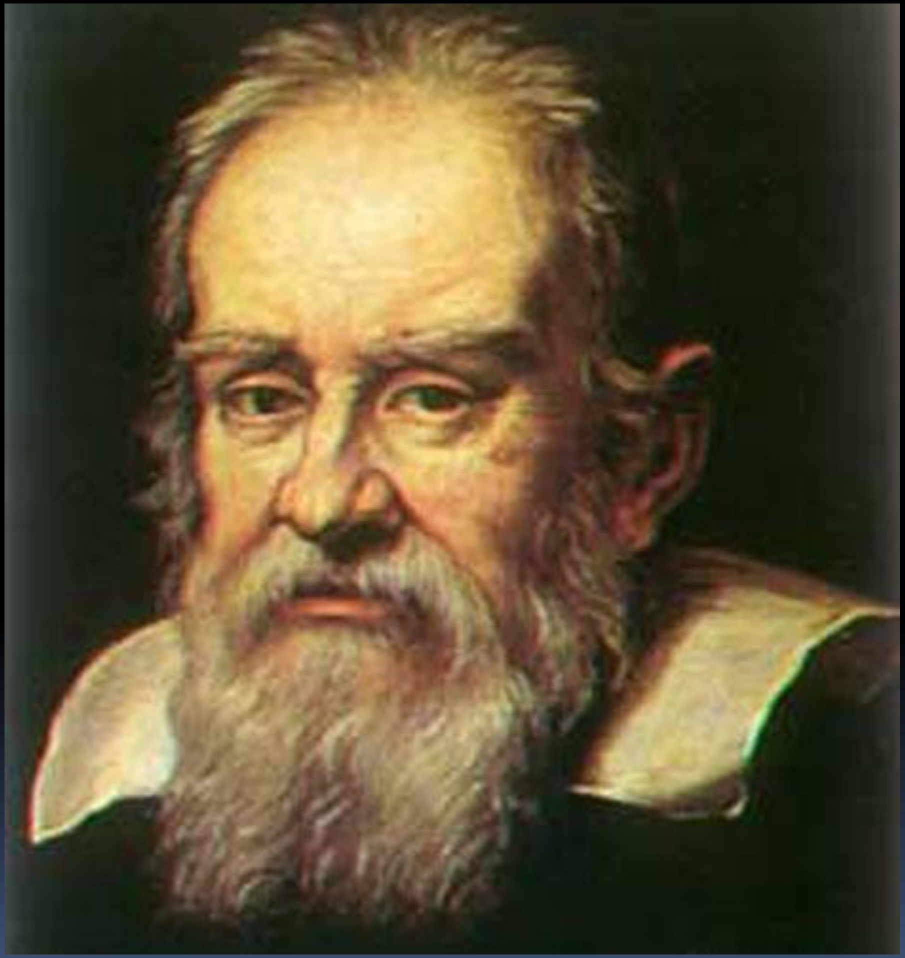
Two Dimensional Projectile Motion – Case 1

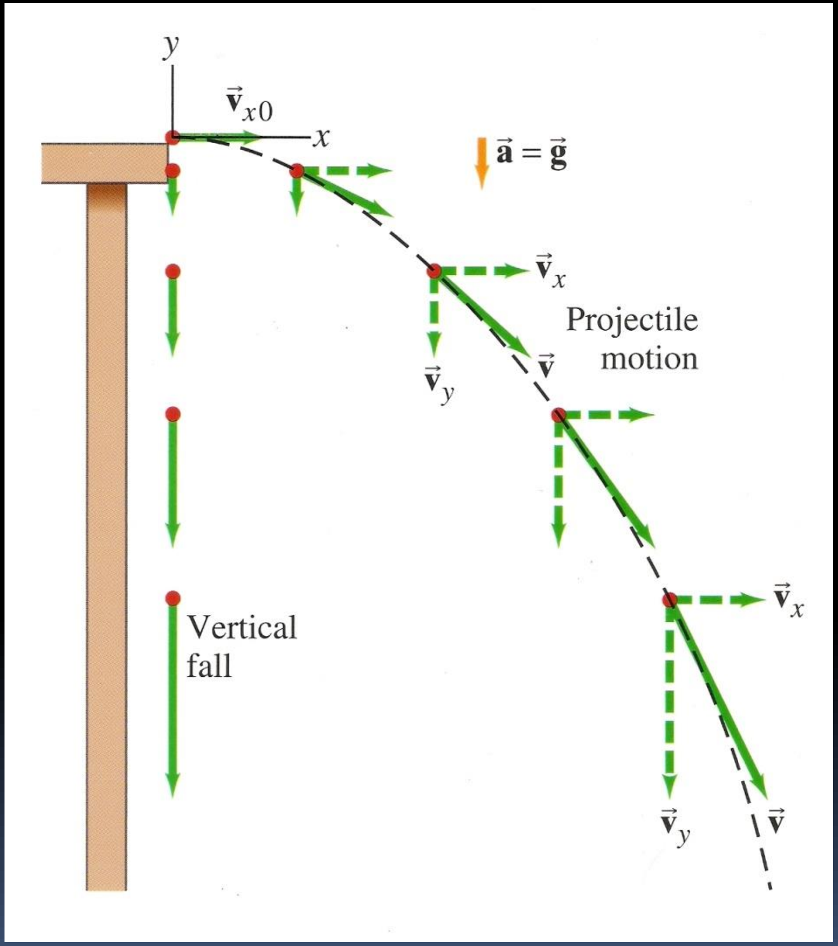


Two Dimensional Projectile Motion – Case 2



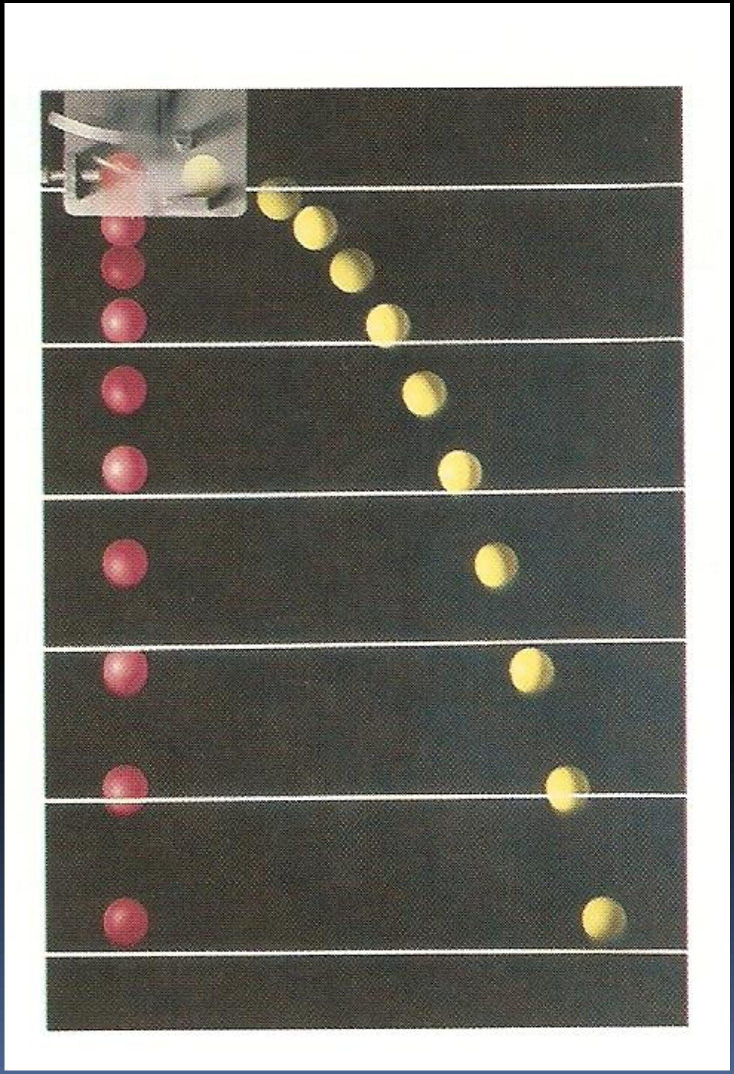
Thanks, Galileo





One Key Finding

- The time it takes for an object to fall from a given height is the same whether it is simply dropped or if it begins with a horizontal velocity.
- Demonstration



Kinematic Equations

Horizontal

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + 1/2\, a_x t^2$$

$$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$$

Vertical

$$v_y = v_{y0} + a_y t$$

$$y = y_0 + v_{y0} t + 1/2\, a_y t^2$$

$$v_y^2 = v_{y0}^2 + 2a_y (y - y_0)$$

Assumptions

- We consider motion only after it has been projected and is moving freely through the air
  - We don't consider the acceleration it took to reach that velocity
- We consider air resistance to be negligible
  - When the object is moving through the air, both horizontally and vertically, it doesn't slow down due to air resistance

Make the Math Easier

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + 1/2\, a_x t^2$$

$$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$$

$$v_y = v_{y0} + a_y t$$

$$y = y_0 + v_{y0} t + 1/2\, a_y t^2$$

$$v_y^2 = v_{y0}^2 + 2a_y (y - y_0)$$

- No horizontal acceleration, horizontal velocity remains constant
- Y-axis positive up, gravity negative down
- Acceleration in Parabolic Motion

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + 1/2\, a_x t^2$$

$$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$$

$$v_y = v_{y0} + a_y t$$

$$y = y_0 + v_{y0} t + 1/2\, a_y t^2$$

$$v_y^2 = v_{y0}^2 + 2a_y (y - y_0)$$

Kinematic Equations for Projectile Motion

$$v_x = v_{x0}$$

$$x = x_0 + v_{x0} t$$

$$v_y = v_{y0} - gt$$

$$y = y_0 + v_{y0} t - 1/2\, g t^2$$

$$v_y^2 = v_{y0}^2 - 2gy$$

Kinematic Equations for Projectile Motion

$$v_x = v_{x0}$$

$$x = x_0 + v_{x0}t$$

$$v = u$$

$$s = ut$$

$$v_y = v_{y0} - gt$$

$$y = y_0 + v_{y0}t - 1/2\,gt^2$$

$$v_y^2 = v_{y0}^2 - 2gy$$

$$v = u + gt$$

$$s = ut + 1/2\,gt^2$$

$$v^2 = u^2 + 2gs$$

$$s = \frac{(v+u)t}{2}$$

Problem Solving Process – Extra Steps

1. Read the problem carefully and draw a picture
2. Choose origin and x-y coordinate system
3. If given an initial velocity, resolve it into x- and y-components.
4. Analyze horizontal (x) and vertical (y) motion separately
5. Continue with problem solving process for kinematic equations

MANIPULATION OF VARIABLES

PROJECTILE MOTION SIMULATOR

Fluid Resistance

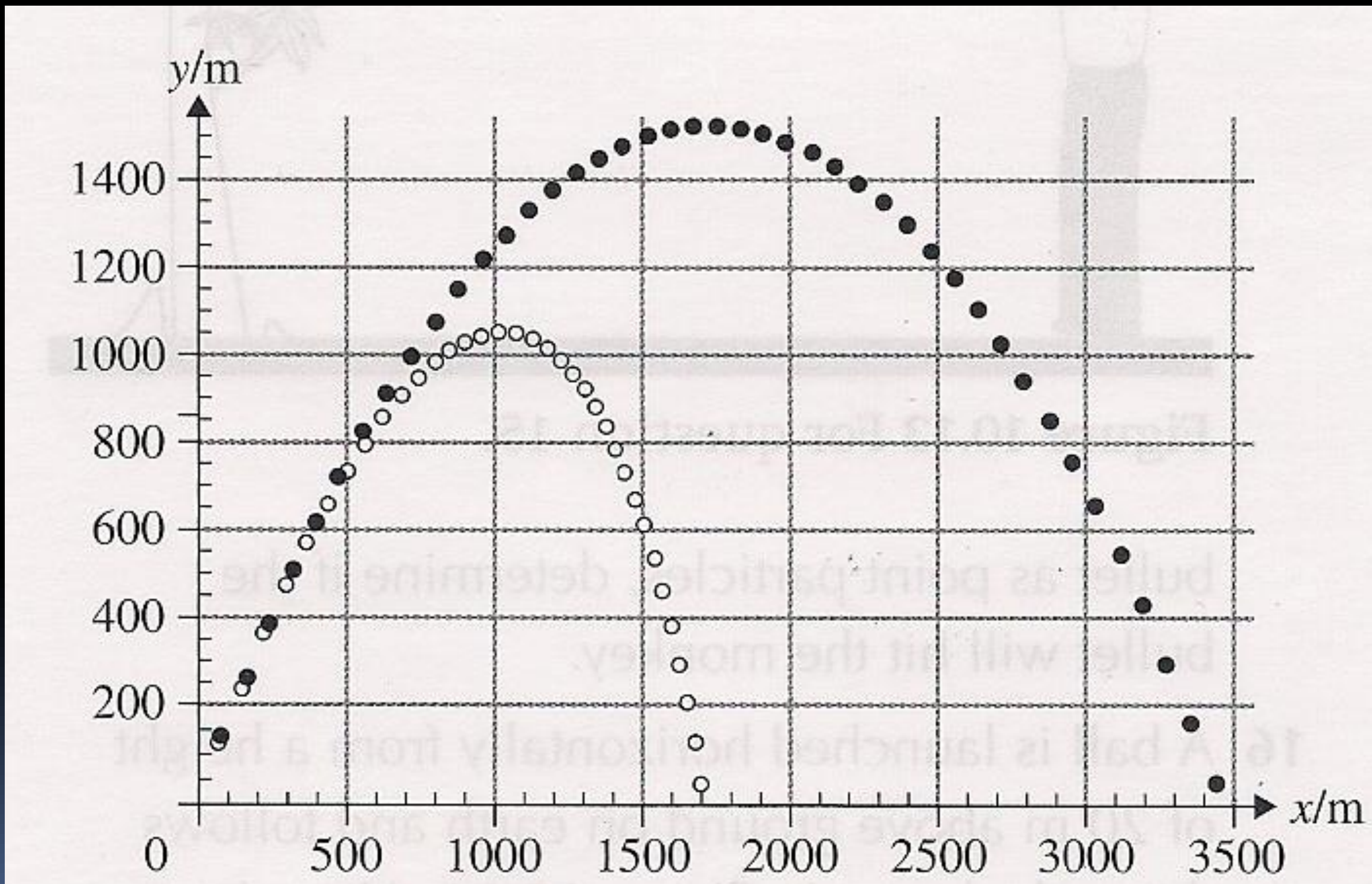
- Fluid resistance, or drag force, acts opposite to the direction of motion.
- The force due to drag is given by the equation (not testable)
- For our purposes, fluid resistance is proportional to velocity at low speeds and velocity squared at high speeds

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

$$F_D = kv$$

$$F_D = kv^2$$

Effect of Fluid Resistance



Fluid Resistance

- Sequence of events:
  - An object starts falling under the force of gravity with acceleration of $9.81\ m/s^2$ and no resistance
  - As velocity increases, fluid resistance increases and acceleration decreases
  - Eventually, the object reaches a speed where ***fluid resistance equals the force of gravity***, acceleration has decreased to zero, and velocity is constant
  - This constant velocity is known as ***terminal velocity*** or ***terminal speed***

Terminal Velocity

- The equation for terminal velocity based on the drag force is given to the right

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

$$F_D = mg$$

$$v_T = \sqrt{\frac{2mg}{\rho C_D A}}$$

- For our purposes, we will assume low speed ($F_D \approx v$) and terminal velocity will be

$$v_T = \frac{2mg}{\rho C_D A}$$

$$k = 1/2\,\rho C_D A$$

$$v_T = \frac{mg}{k}$$

Data Booklet Reference:

$$v = u + at$$

$$s = ut + 1/2\,at^2$$

$$v^2 = u^2 + 2as$$

$$s = \frac{(v + u)t}{2}$$

Applications And Skills:

- Analyzing projectile motion, including the resolution of vertical and horizontal components of acceleration, velocity and displacement.
- Qualitatively describing the effect of fluid resistance on falling objects or projectiles, including reaching terminal speed.

Understandings:

- Projectile motion
- Fluid resistance and terminal speed

Essential Idea:

- Motion may be described and analyzed by the use of graphs and equations.

Questions?

Homework

Pg. 56-57, #25-33

Weightlessness

- On Skis
- On A Motorcycle
- Sphere of Death