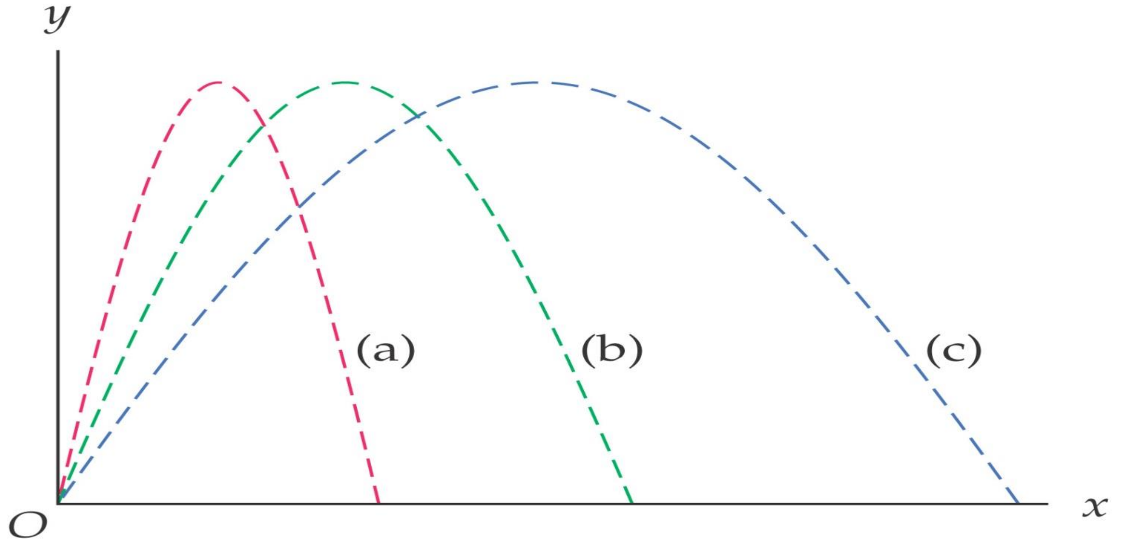
Chapter -4

Two-Dimensional Kinematics



Chapter 4

Two-Dimensional Kinematics

Equations of Motion in 2D:

For X:

① $x_f = x_i + v_{ix} t$

② $x_f = x_i + v_{ix} t + \frac{1}{2} a_x t^2$

③ $v_{fx} = v_{ix} + a_x t$

④ $v_{fx}^2 = v_{ix}^2 + 2 a_x \Delta x$

For Y:

① $y_f = y_i + v_{iy} t$

② $y_f = y_i + v_{iy} t + \frac{1}{2} a_y t^2$

③ $v_{fy} = v_{iy} + a_y t$

④ $v_{fy}^2 = v_{iy}^2 + 2 a_y \Delta y$

Units of Chapter 4

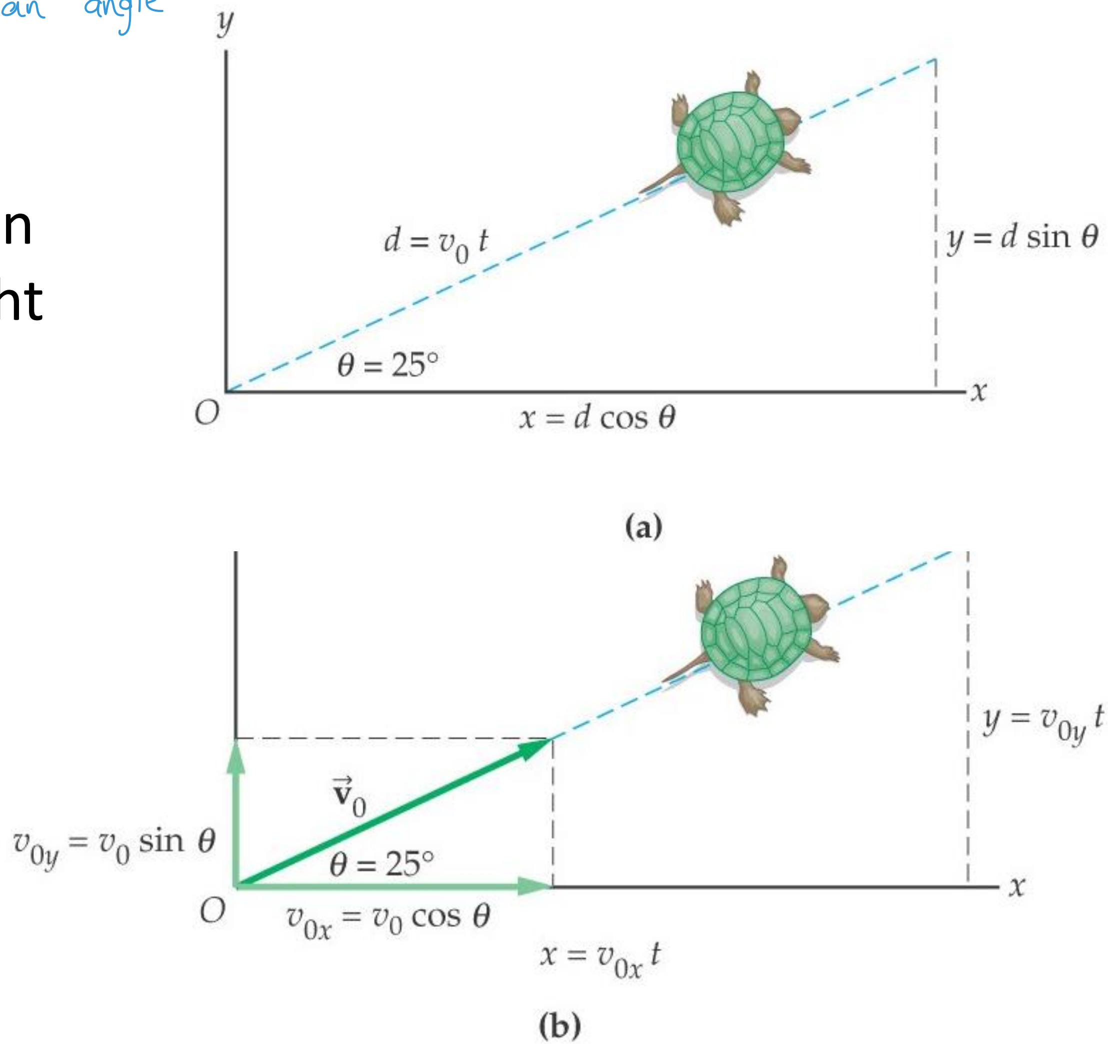
- Motion in Two Dimensions
- Projectile Motion: Basic Equations 2D Two types:
- 1 Zero Launch Angle
- 2 General Launch Angle
- Projectile Motion: Key Characteristics

4-1- Motion in Two Dimensions

Because there is an angle

it is in 2D

If velocity is constant, motion is along a straight line:



4-1- Motion in Two Dimensions

$\theta = 25^\circ$

$t_i = 0\,s$

$t_f = 50\,s$

$\vec{v} = 0.26\,m/s$

$\vec{d} = ?$

① First Way:

$\vec{d} = \vec{v} \times t$

$d = 0.26 \times 5 = 1.3\,m$

$d_x = 1.3 \cos 25 = 1.2\,m$

$d_y = 1.3 \sin 25 = 0.55\,m$

② Second Way:

$d_x = v_x \times t$

$(|v|\cos\theta) \times t$

$(0.26 \cos 25) \times 0.5 =$ $1.2\,m$

$d_y\ v_y \times t$

$(|v|\sin\theta) \times t$

$(0.26 \sin 25) \times 0.5 =$ $0.55\,m$

Example:4-1

- An eagle perched on a tree limb 19.5m above the water spots at a fish swimming near the surface. The eagle pushes off from the branch and descends towards the water. By adjusting its body in flight, the eagle maintains a constant speed of 3.10m/s at an angle of 20.0^{0}. below the horizontal.

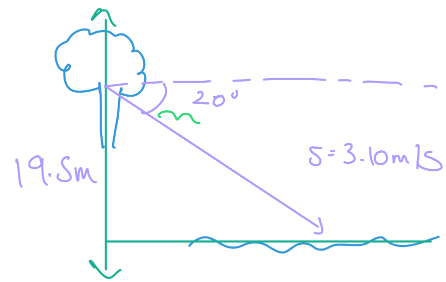
A) How long does it take for the eagle to reach the water? Ans:18.4s

B) How far has the eagle travelled in the horizontal direction when it reaches the water? Ans:53.5m

Example:4-1

Speed: 3.10 m/s $|v_i| = 3.10\ m/s$

$y_i = 19.5\ m$ $y_f = 0$ $\theta = 20°$



A) $T = ?$

$$y_f = y_i + v_{iy}\, t$$

$$t = \frac{y_f - y_i}{v_{iy}} = \frac{0 - 19.5}{-(3.10 \sin 20)} = 18.4\,s$$

the falcon is going down

B) $x_f = x_i + v_{ix}\, t$

$$x_f = 0 + (3.10 \cos 20)\, 18.4$$

$$= 53.6\ m$$

4-1 -Motion in Two Dimensions

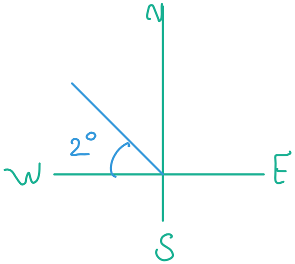
Motion in the *x*- and *y*-directions should be solved separately:

TABLE 4–1 Constant-Acceleration Equations of Motion

Position as a function of time	Velocity as a function of time	Velocity as a function of position
$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$	$v_x = v_{0x} + a_x t$	$v_x^2 = v_{0x}^2 + 2a_x\Delta x$
$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$	$v_y = v_{0y} + a_y t$	$v_y^2 = v_{0y}^2 + 2a_y\Delta y$

Problem 2

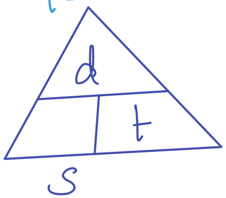
- Q2. A sails boat runs before the wind with a constant speed of 4.2m/s in the direction of 32^0 north of west. How far
- (a)west and
- (b) North has the sailboat travelled in 25min
- Sol:-



$= |v_i| = 4.2 \, m/s$

$S \quad 25m \times \frac{60 s}{1 m} = 1500$

$t =$



Problem 2

$d_{speed} = speed_x \times t$

$\vec{d} = v_i \cos t$

$\vec{d} = -(4.2) \cos 32 \cdot 1500$

$= -5434 \, m$

$d_{speed} = speed_{North} \times t$

$d_{speed} = speed_y \times t$

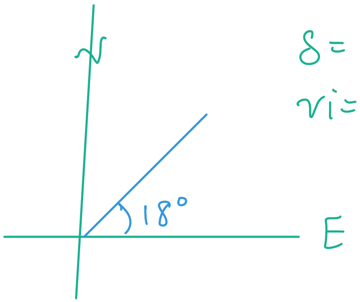
$\vec{d} = v_i \sin t$

$\vec{d} = (4.2) \sin 32 \cdot 1500$

$= 3338 \, m$

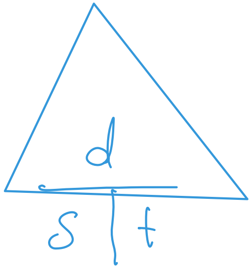
Problem 3

- Q3) As you walk to class with a constant speed of 1.75m/s, you are moving in a direction that is 18^0 north of east. How much time does it take to change your displacement by
- (a) 20.0m east or
- (b) 30.0m north
- Q4)---Assignment(pg 104)



$s = 1.75$
$v_i = 1.75$

Problem 3



a) $\text{time}_{east} = \dfrac{dx}{\text{speed}_x} = \dfrac{20\,m}{1.75\cos 18} = 12.s$

b) $\text{time North} = \dfrac{dy}{\text{speed}_y} = \dfrac{30\,m}{1.75\sin 18} = 55.5s$

or we can use:

$x_f = x_i + v_{ix}\,t \rightarrow \Delta x = v_{ix}\,t$

- Q4)---Assignment(pg 104)

$y_f = y_i + v_{iy}\,t \rightarrow \Delta y = v_{iy}\,t$

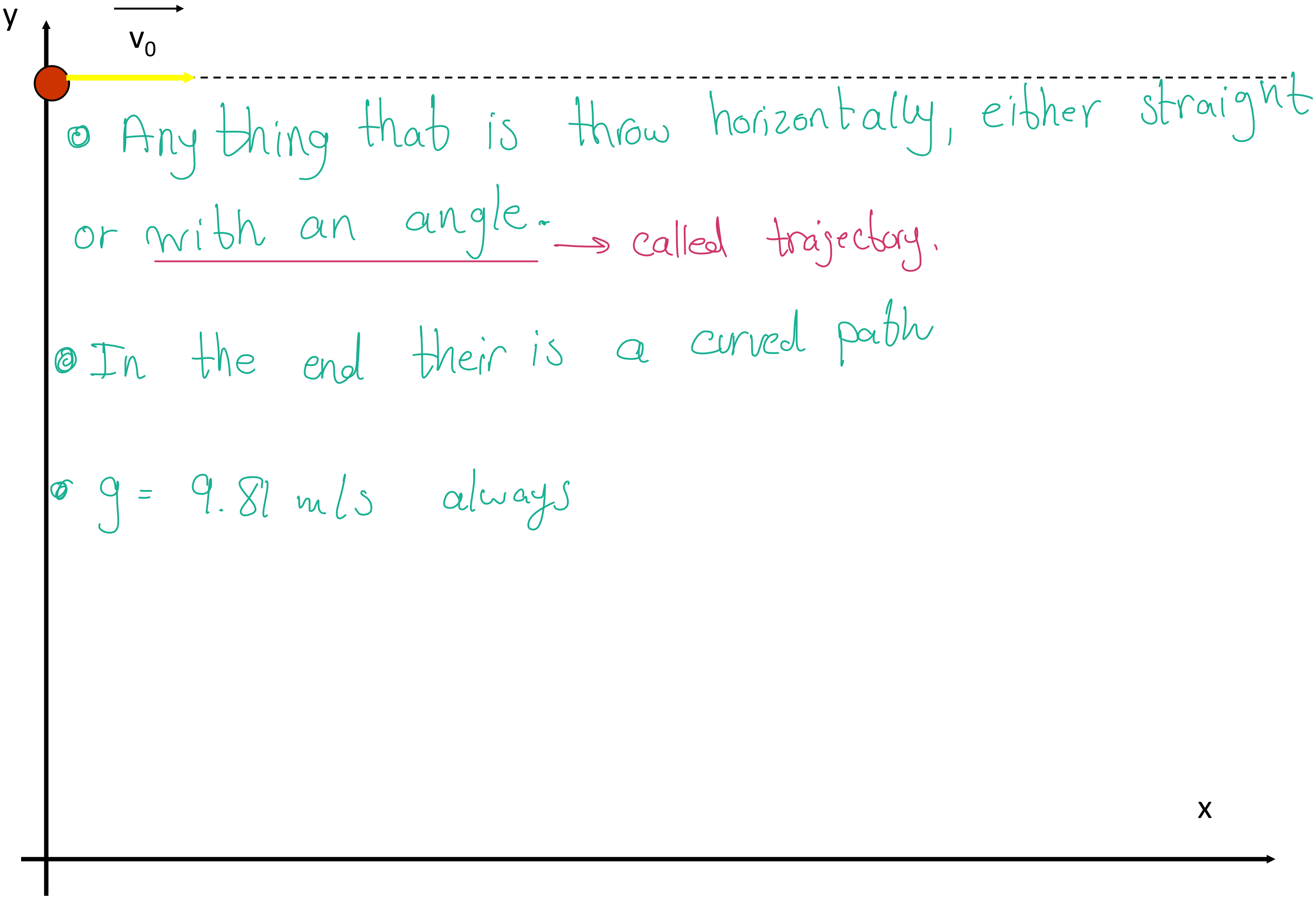
Part 1.

Motion of Objects Projected Horizontally

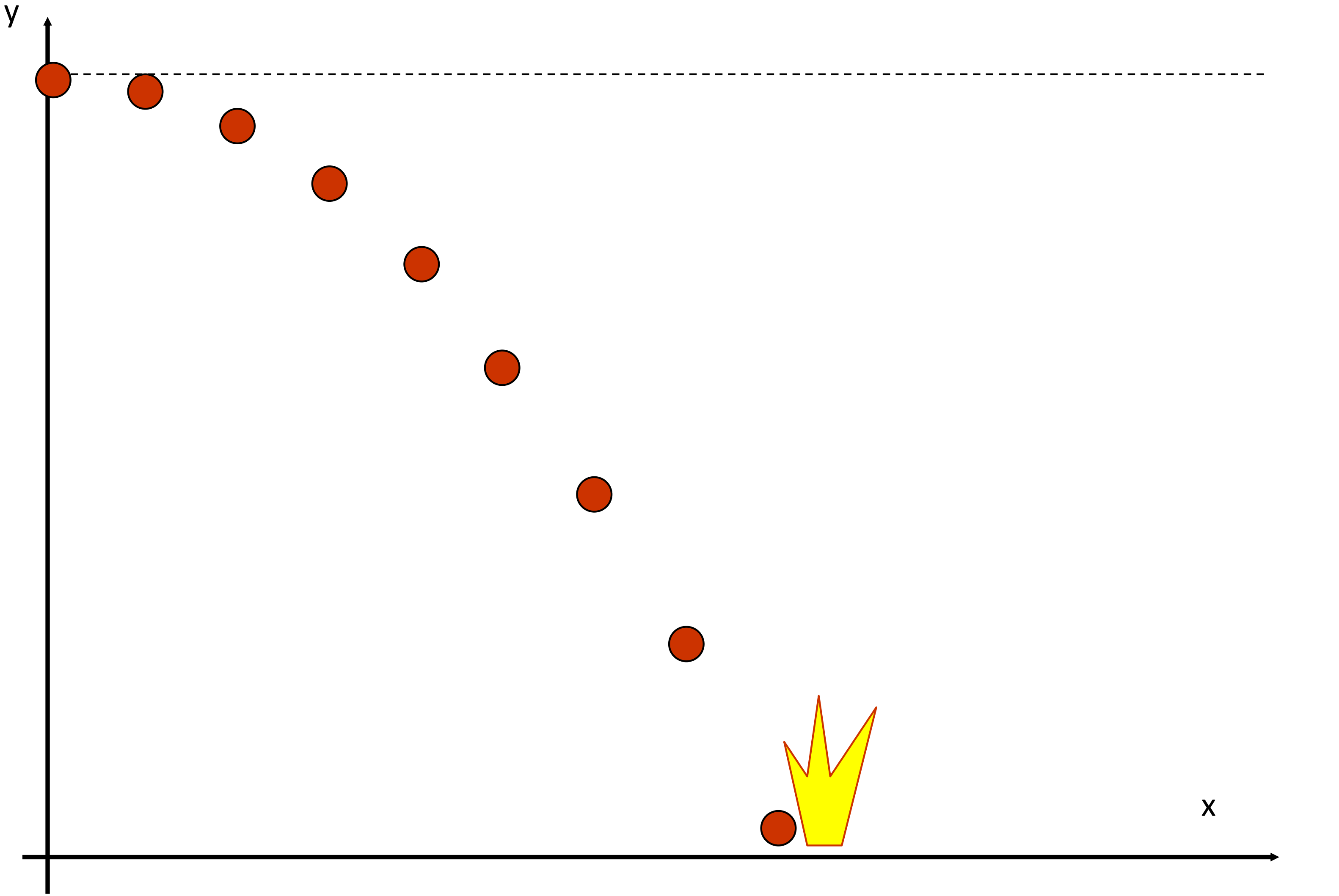
PROJECTILE is a body which is thrown horizontally or at an angle relative to the horizontal which follows a curved path called **trajectory**

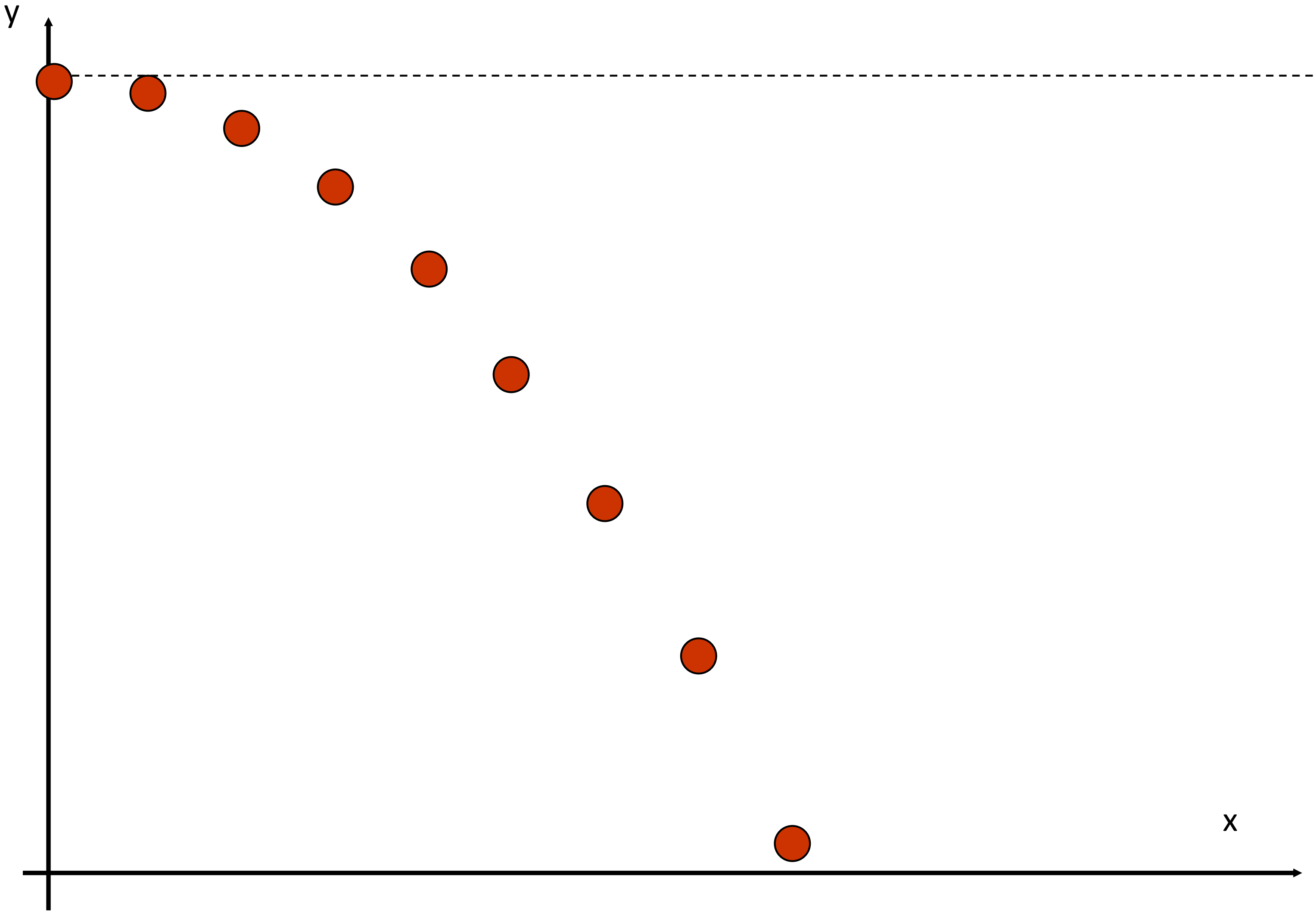
Examples:

Ball being thrown, water coming out of the hose, a bullet fired from a gun, arrow shot from a bow, cannonballs, fountains.



- Any thing that is throw horizontally, either straight or with an angle. → called trajectory.
- In the end their is a curved path
- $g = 9.81$ m/s always


y
x


y
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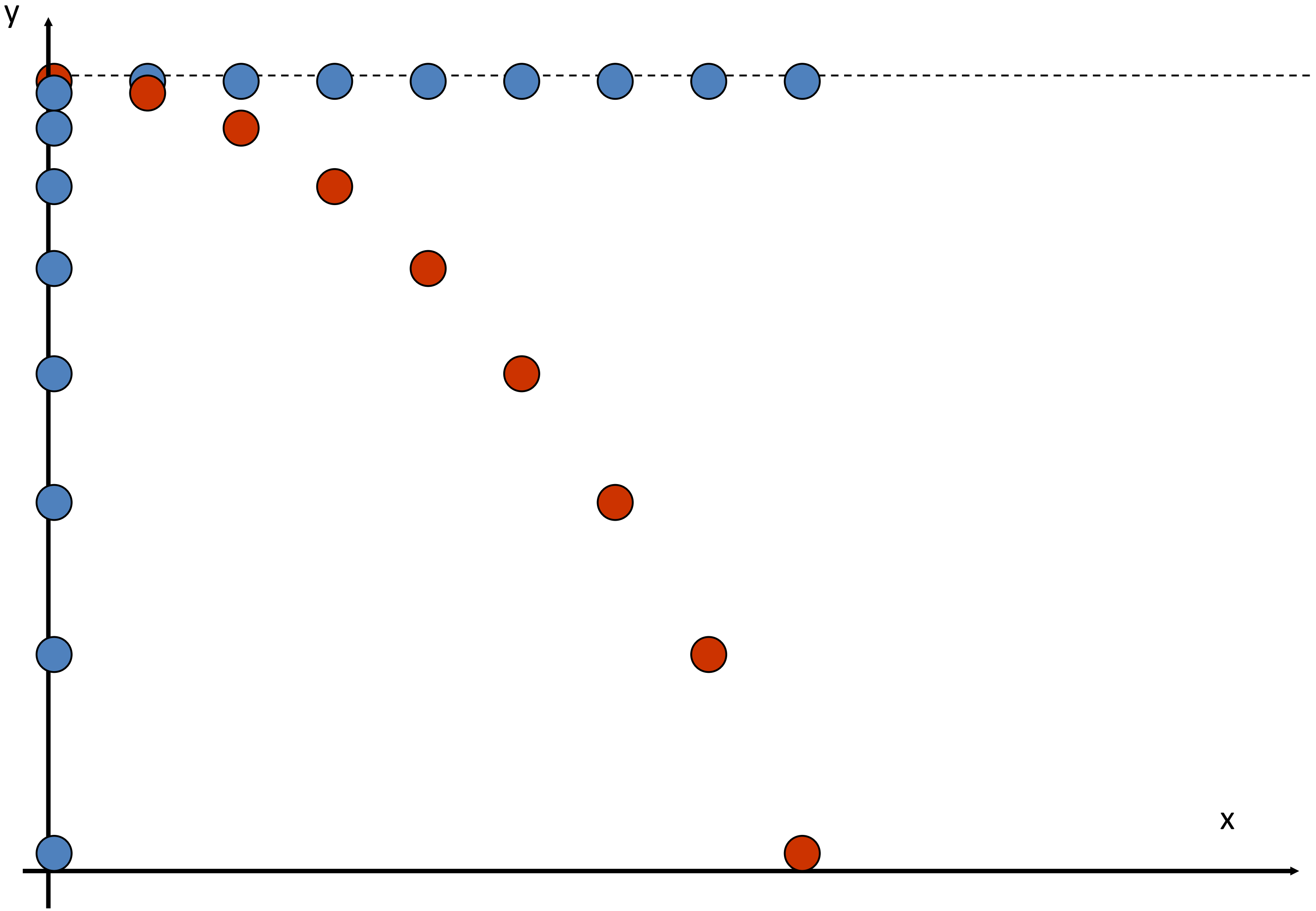
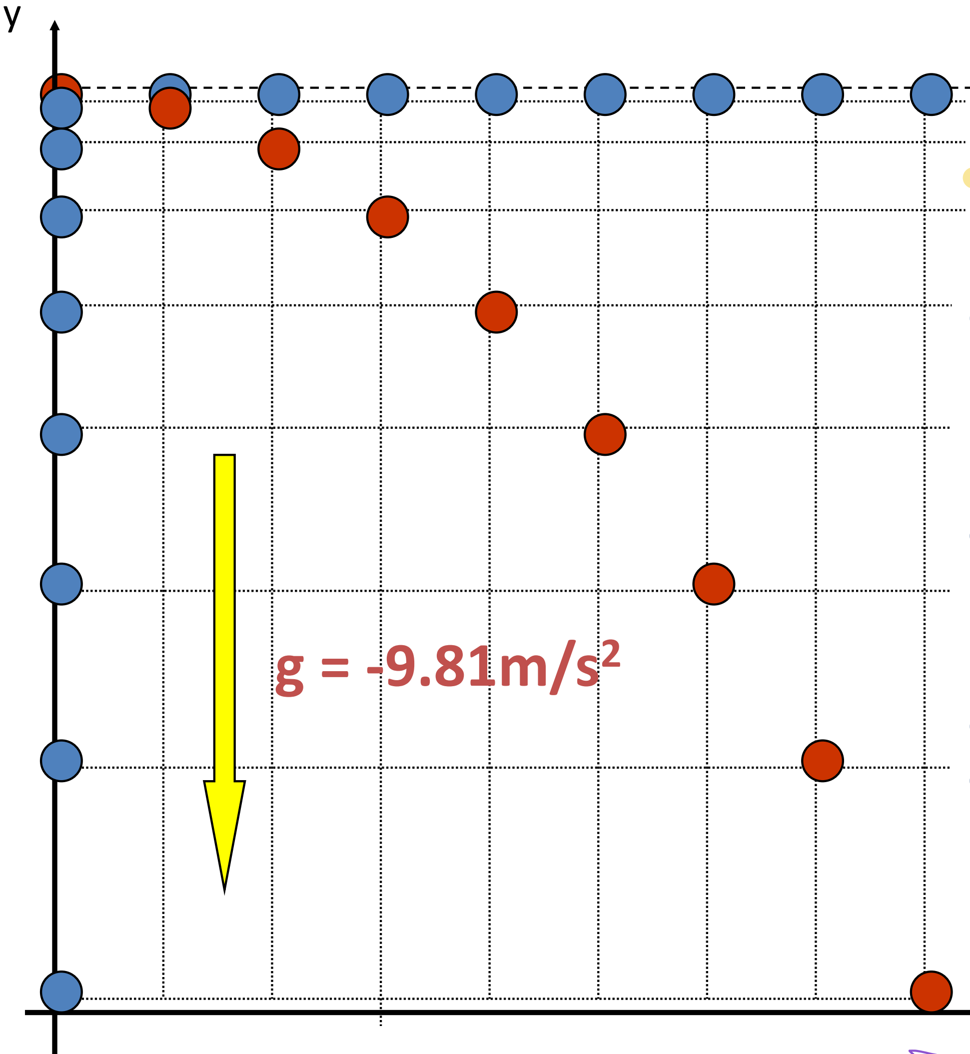

y
x



in y- axis

- **Motion is accelerated**
- **Acceleration is constant, and downward**
- **$a = g = -9.81 m/s^2$**
- **The horizontal (x) component of velocity is constant** → v_{ix} = constant
- **The horizontal and vertical motions are independent of each other, but they have a common time**

$t_x = t_y$

other than that everything is different.

v_{ix} = constant, so $a_x = 0$

v_{iy} = changing, so $a_y = -9.81\ m/s^2$

ANALYSIS OF MOTION

ASSUMPTIONS:

- x-direction (horizontal): $\longrightarrow$ uniform motion constant = 0
- y-direction (vertical): $\longrightarrow$ accelerated motion $= -9.81 m/s^2$
- no air resistance or earth rotation.

QUESTIONS:

- What is the trajectory? Curved path
- What is the horizontal range? Displacement in x axis
- What is the final velocity of the projectile? v_{ix} = ?

  v_{iy} = ?

  2 final velocities.

4-2 -Projectile Motion: Basic Equations

Projectile is an object that is launched into motion and then allowed to follow a path determined solely by the influence of gravity.

Assumptions:

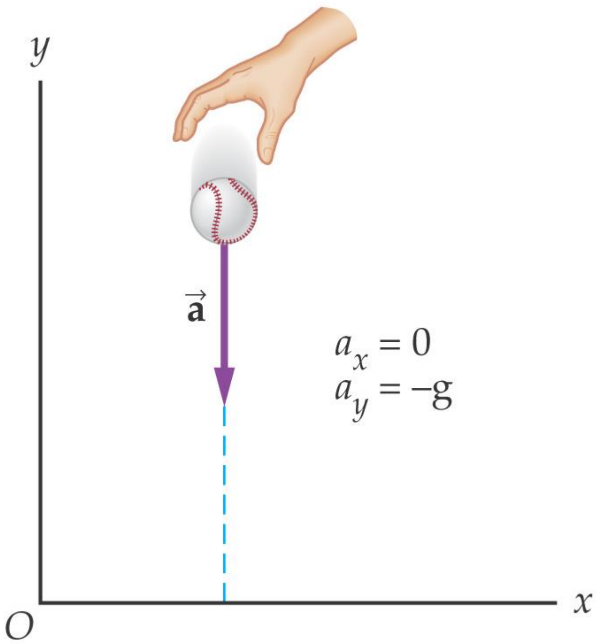
- ignore air resistance
- ignore Earth's rotation
- g = 9.81 m/s^2, downward → $v_{iy} =$

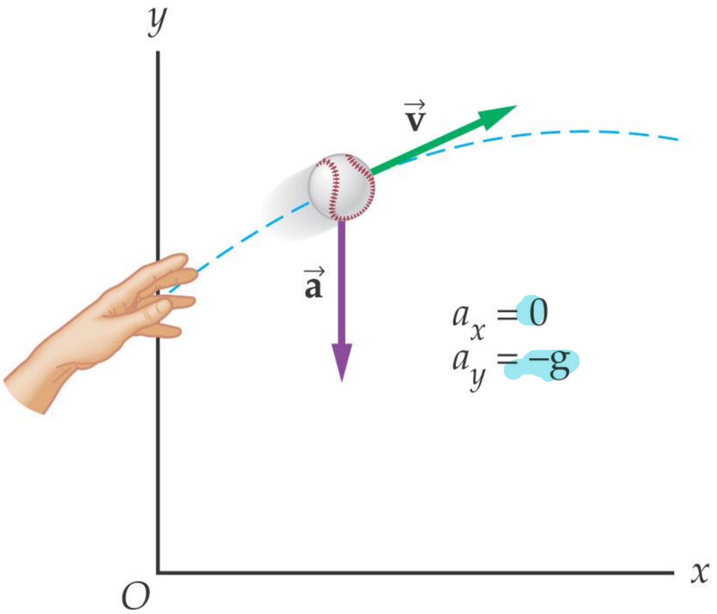
ignore Earth's rotation

If y-axis points upward, acceleration in x-direction is zero and acceleration in y-direction is -9.81 m/s^2

4-2- Projectile Motion: Basic Equations

The acceleration is independent of the direction of the velocity: even if a= +, that doesn't mean velocity is positive





4-2 -Projectile Motion: Basic Equations

These, then, are the basic equations of projectile motion:

$$x = x_0 + v_{0x}t$$
$$y = y_0 + v_{0y}t - \tfrac{1}{2}gt^2$$

$$v_x = v_{0x}$$
$$v_y = v_{0y} - gt$$

$$v_x{}^2 = v_{0x}{}^2$$
$$v_y{}^2 = v_{0y}{}^2 - 2g\Delta y$$

4-2 -Projectile Motion: Basic Equations

X-axis:

g y

$$x_f = x_i + v_{ix} t + \frac{1}{2} a_x t^2$$

one, wh ? a = 0

gone, why? a=0

$$v_{fx} = v_{ix} + a_x t$$

gone, why? a=0

$$v_{fx}^2 = v_{ix}^2 + 2 a_x \Delta x$$

y-axis:

$$y_f = y_i + v_{iy} t + \frac{1}{2} g t^2$$

$$v_{fy} = v_{iy} + g t$$

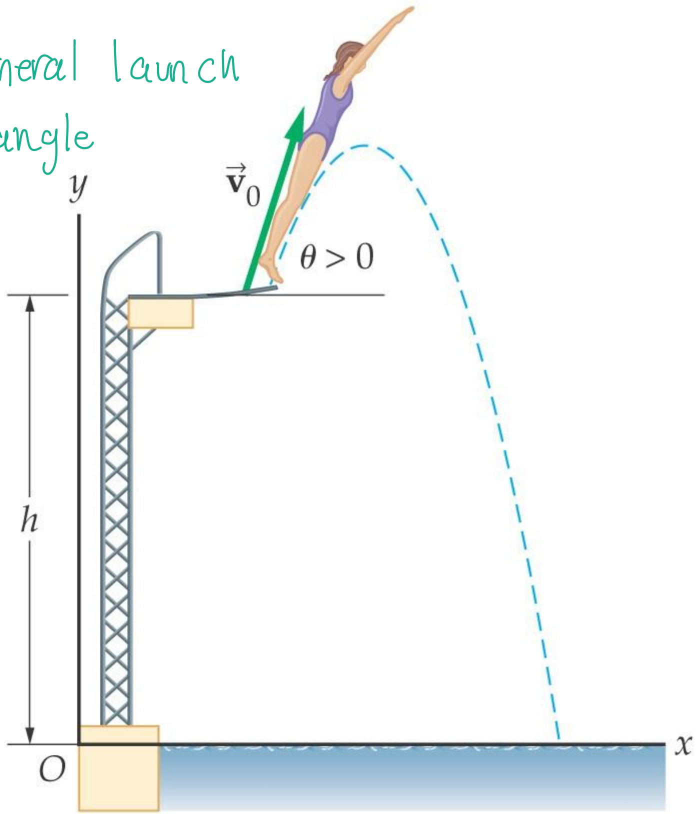
$$v_{fy}^2 = v_{iy}^2 + 2 g \Delta y$$

all a are changed to $g = 9.81\ m/s^2$

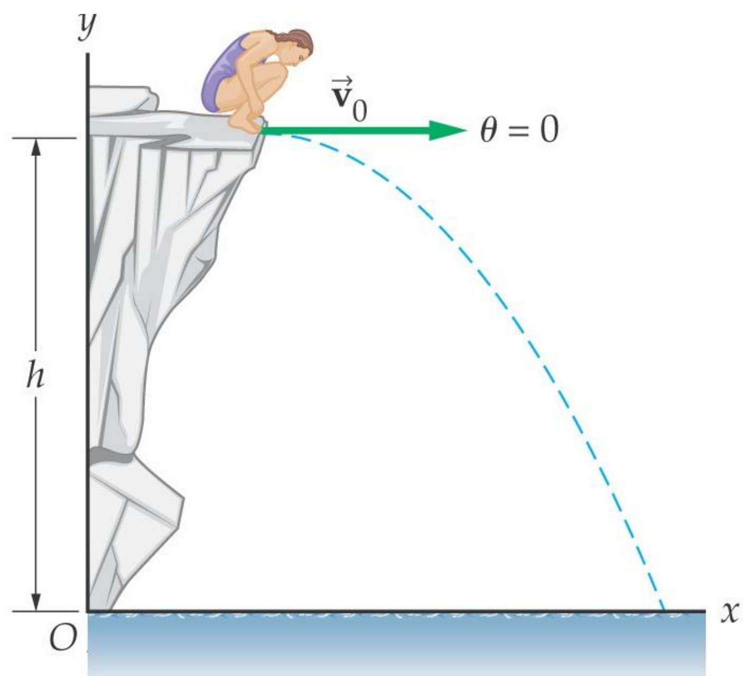
4-3 -Zero Launch Angle

Launch angle: direction of initial velocity with respect to horizontal

general launch angle



zero launch angle



4-3- Zero Launch Angle

In this case, the initial velocity in the *y*-direction is zero. Here are the equations of motion, with $x_0 = 0$ and $y_0 = h$:

, this is the difference:

- $v_{ix} = v_i \cos(\theta) = v_i(1) = v_i \longrightarrow v_{ix} = v_i$
- $v_{iy} = v_i \sin(\theta) = v_i(0) = 0 \longrightarrow v_{iy} = 0$
- $x_i = 0$
- $y_i = h$

$$x = v_0 t$$

$$y = h - \frac{1}{2} g t^2$$

$$v_x = v_0 = \text{constant} \qquad {v_x}^2 = {v_0}^2 = \text{constant}$$

$$v_y = -gt \qquad {v_y}^2 = -2g\Delta y$$

4-3- Zero Launch Angle

X axis:

$xf = vi\, t$

$vf_x = vix$

$vf_x^2 = vix^2$

y axis:

$yf = h + \frac{1}{2} - g\, t^2$

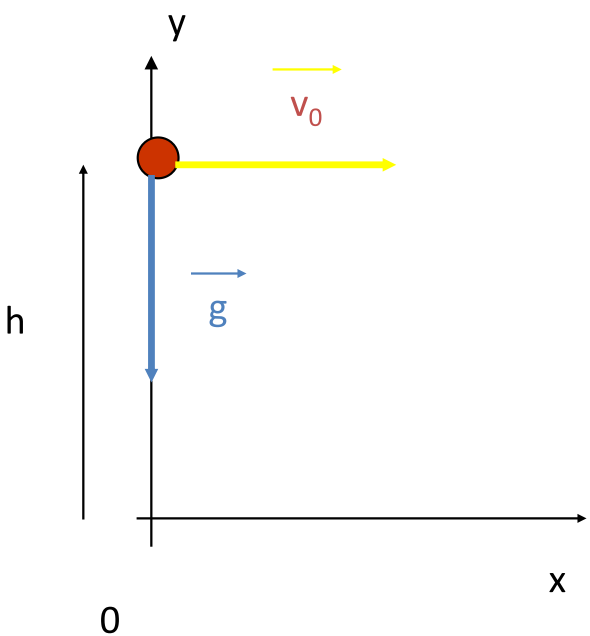
$vf_x = -g\, t$

$vf_x^2 = 2 - g\, \Delta y$

$$v_y = -gt$$

$$v_y{}^2 = -2g\Delta y$$

Frame of reference:



Equations of motion:

	X Uniform m.	Y Accel. m.
ACCL.	$a_x = 0$	$a_y = -g = -9.81\ m/s^2$
VELC.	$v_x = v_0$	$v_y = -g\ t$
DSPL.	$x = v_0\ t$	$y = h - \frac{1}{2}\ g\ t^2$

Zero launch angle, why? Because there is height.

Example 4-3

- A person skateboarding with a constant speed of 1.30m/s releases a ball from a height of 1.25m above the ground. Given that $x_0 = 0$
- and $y_0 = h = 1.25$m, Find x and y for
- (a) t = 0.250s and
- (b) t= 0.500s

- (c) Find the velocity, speed and direction of motion of ball at t=0.500s
- Sol: (a) x= 0.325m , y= 0.943m
- (b) x= 0.650m , y= 0.0238m
- (c) v_x= 1.30m/s, v_y= -4.91m/s , Speed=5.08m/s , Direction= -75.2°

$1.30 \times 0.25 = 0.33m$

a $y_f = h + v_i t + \frac{1}{2} - g t$

$1.25 - (\frac{1}{2} \times 9.81 \times (0.25)^2) = 0.943m$

b) $x_f = v_i t$

$= 1.30 \times 0.5 = \longrightarrow$

$y_f = h + \frac{1}{2} - g t$

$1.25 - (\frac{1}{2} \times 9.81 \times (0.5)^2)$

=

$a_x = 0$

$a_y = -g$

Projecti Zero launch

$y_i = h$

$v_{ix} = v_i$

$v_{iy} = 0$

$x_i = 0$

- (c) v_x= 1.30m/s, v_y= -4.91m/s , Speed=5.08m/s , Direction= -75.2°

le

c)

$v_{fx} = v_i$

$= 1.30\ m/s$

$v_{fy} = -g\,t$

$= -9.81 \times 0.5 = -4.905$

$\text{Speed} = \sqrt{(v_{fx})^2 + (v_{fy})^2}$

$= \sqrt{(1.30)^2 + (-4.9)^2} = 5.1\ m/s$

$\theta_v = \tan^{-1}\left(\frac{v_{fy}}{v_{fx}}\right) =$

$= \tan^{-1}\left(\frac{-4.9}{1.30}\right) = -75^\circ$ fourth Quarter

$a_x = 0$

$a_y = -g$

Projectile zero launch

$y_i = h$

$v_{ix} = v_i$

$v_{iy} = 0$

$x_i = 0$

- (c) v_x= 1.30m/s, v_y= -4.91m/s , Speed=5.08m/s , Direction= -75.2°

4-4- General Launch Angle

$x_i = y_i = 0$

$v_{ix} = v_i \cos\theta$

$v_{iy} = v_i \sin\theta$

In general, $v_{0x} = v_0 \cos\vartheta$ and $v_{0y} = v_0 \sin\vartheta$

This gives the equations of motion:

$$x = (v_0 \cos\theta)t$$

$$y = (v_0 \sin\theta)t - \frac{1}{2}gt^2$$

$$v_x = v_0 \cos\theta \qquad\qquad {v_x}^2 = {v_0}^2 \cos^2\theta$$

$$v_y = v_0 \sin\theta - gt \qquad\qquad {v_y}^2 = {v_0}^2 \sin^2\theta - 2g\Delta y$$

4-4- General Launch Angle

$x_i = y_i = 0$

In general, $v_{0x} = v_0 \cos \vartheta$ and $v_{0y} = v_0 \sin \vartheta$

$v_{ix} = v_i \cos \theta$

$v_{iy} = v_i \sin \theta$

$$v_y = v_0 \sin \theta - gt \qquad v_y{}^2 = v_0{}^2 \sin^2 \theta - 2g\Delta y$$

General → because it starts from the origin

Exercise: 4-1

+ there is an angle

- A projectile is launch from the origin with an initial speed of 20.0m/s at an angle of 35.00 above the horizontal. Find the x and y positions of the projectile at times
- (a) t= 0.500s Sol:- x= 8.19m, y=4.51m Just replace → time
- (b) t=1.00s Sol:- x= 16.4m , y= 6.57m
- (c) t= 1.50s Sol:- x= 24.6m , y=6.17m Just replace → time

2D → Projectile → $a_x = 0$, $a_y = g$

General launch → $x_i = y_i = 0$, $v_{ix} = v_i \cos(\theta)$, $v_{iy} = v_i \sin(\theta)$

a) $x_f = (v_i \cos\theta)\, t$

$= 20 \cos 35 \times 0.5 \rightarrow 8.2\ m$

$y_f = (v_i \sin\theta)\, t - \frac{1}{2} g t^2$

$= 20 \sin 35 \times 0.5 - \left(\frac{1}{2} \times 9.81 \times (0.5)^2\right) \rightarrow 4.5\ m$

b) $x_f = (v_i \cos\theta)\, t$

$= 20$

• (c) t= 1.50s   Sol.- x= 24.6m , y=6.17m

Exercise 4-2

- Referring to ex-4-1 ,find the velocity of the projectile at times
- (a)t= 0.500s Sol:- **V**= (16.4m/s)i + (6.57m/s)j
- (b) t=1.00s Sol:- **v** = (16.4m/s)i +(1.66 m/s)j
- (c) t= 1.50s Sol:- **v**=(16.4m/s)i + (-3.24 m/s)j

unit vector
notation

Exercise 4-2

a) $v_{fx} = v_i \cos\theta$

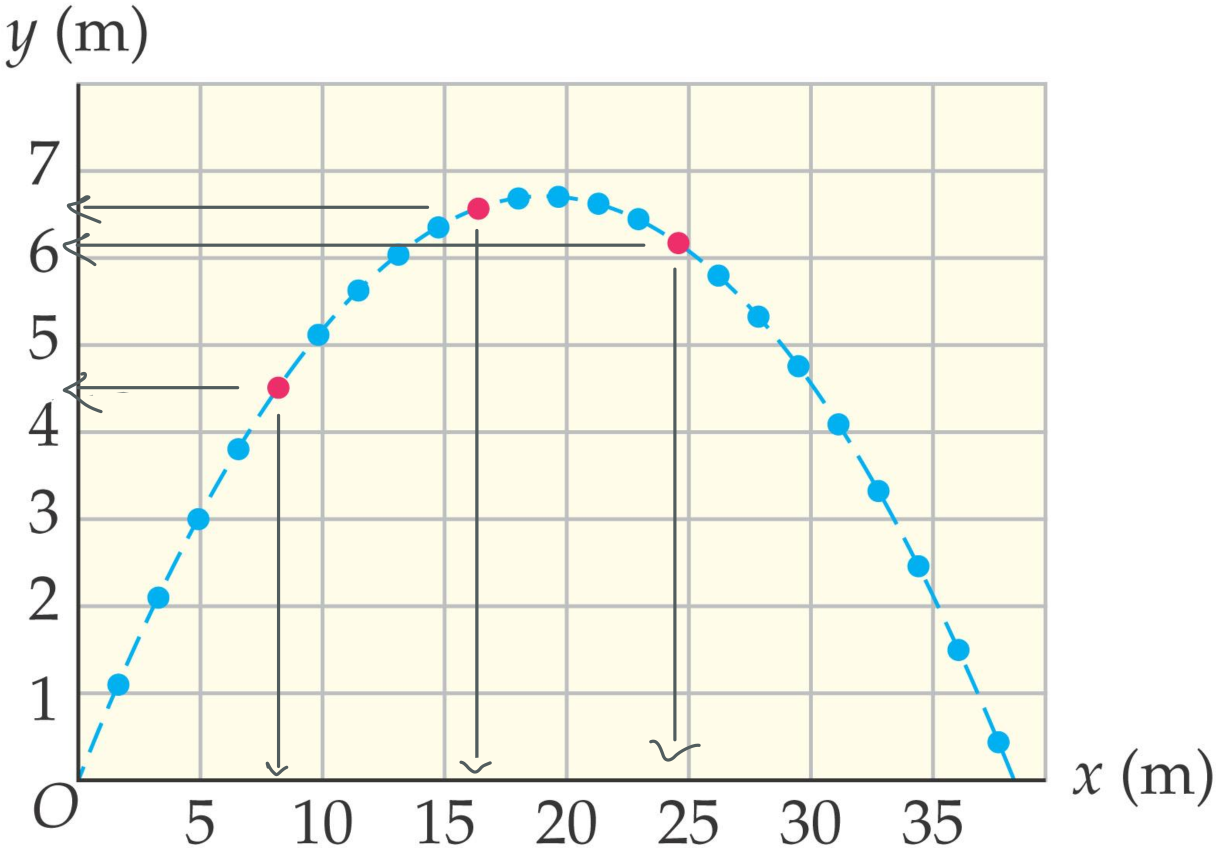
$= 20 \cos 35 = (16.4 \text{ m/s})\hat{x}$

$v_{fy} = v_i \sin\theta - gt$

$= 20 \sin 35 - (9.81)(0.5) = (6.6 \text{ m/s})\hat{y}$

4-4- General Launch Angle

Snapshots of a trajectory; red dots are at t = 1 s, t = 2 s, and t = 3 s



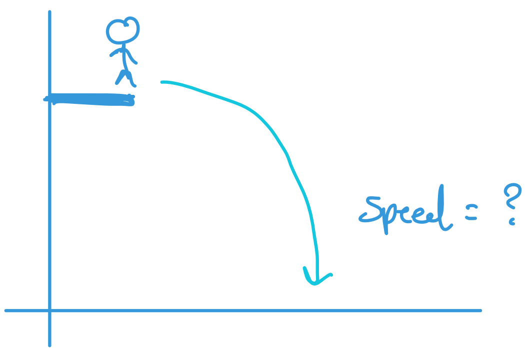
2D → projectile → zero launch, because there is h, →

Problem: 12

$x_i = 0$ $v_{ix} = v_i$

$y_i = h$ $v_{iy} = 0$

- A diver runs horizontally off the end of diving board with an initial speed of 1.85m/s. If the diving board id 3.00m above the water, what is the divers speed just before she enters the water?
- Sol: $V_y^2 = 58.9 m^2/s^2$
- Speed = 7.89m/s



$v_{fx} = v_i$

$v_{fx} = \sqrt{v_i^2} \rightarrow v_{fx} = \sqrt{1.85^2} = 1.85 \text{ m/s}$

$v_{fy}^2 = -2g(y_f - y_i)$

$v_{fy} = \sqrt{(-2)(9.81)(0-3)} = 7.7 \text{ m/s}$

Speed = magnitude = $\sqrt{(v_{fx})^2 + (v_{fy})^2}$

$= \sqrt{(1.85)^2 + (7.7)^2} = 7.9 \text{ m/s}$

General launch, because there is an angle

$x_i = y_i = 0$

Problem 31

$v_{ix} = v_i \cos\theta =$

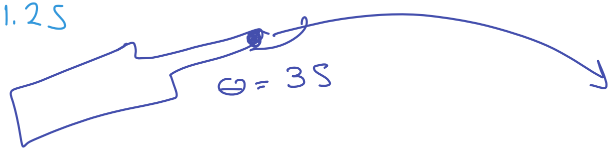
$v_{iy} = v_i \sin\theta =$

- A cork shoots out of a champagne bottle at an angle of 35.0^0 above the horizontal. If the cork travels a horizontal distance of 1.30m in 1.25s,what was its initial speed.

Speed $|v_i| =$

$\Delta x = 1.30\,m$

$t = 1.25$



$V_x = 1.04$ m/s

$V_0 = 1.27$ m/s

$$\frac{x_f}{\cos\theta t} = \frac{v_i \cos\theta\, t}{\cos\theta\, t} =$$

$$v_i = \frac{x_f}{\cos\theta\, t} = \frac{1.30}{\cos 35 \times 1.2\,s} = 1.3\,m/s$$

$$v_0 = 1.27\ m/s$$

2

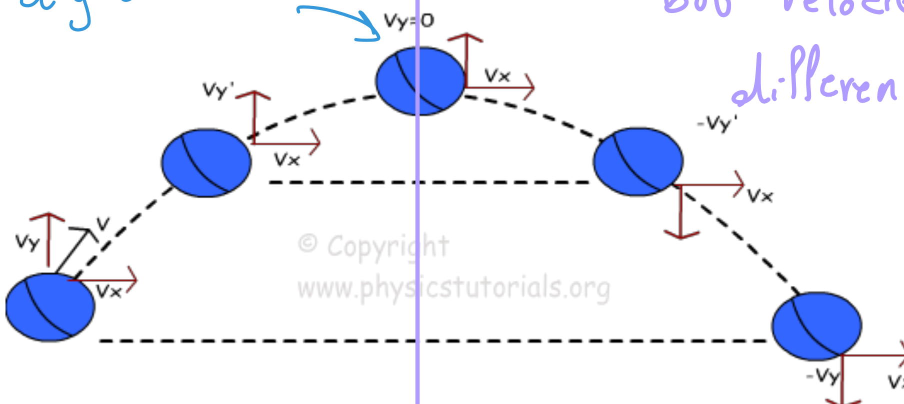
$v_{fy} = 0$

Symmetry

speed is the same, but velocity is different

for v_{fy} & v_{iy}

$v_{fy} = v_{iy} + a_y t$



$v_{iy} = v_i \sin\theta$

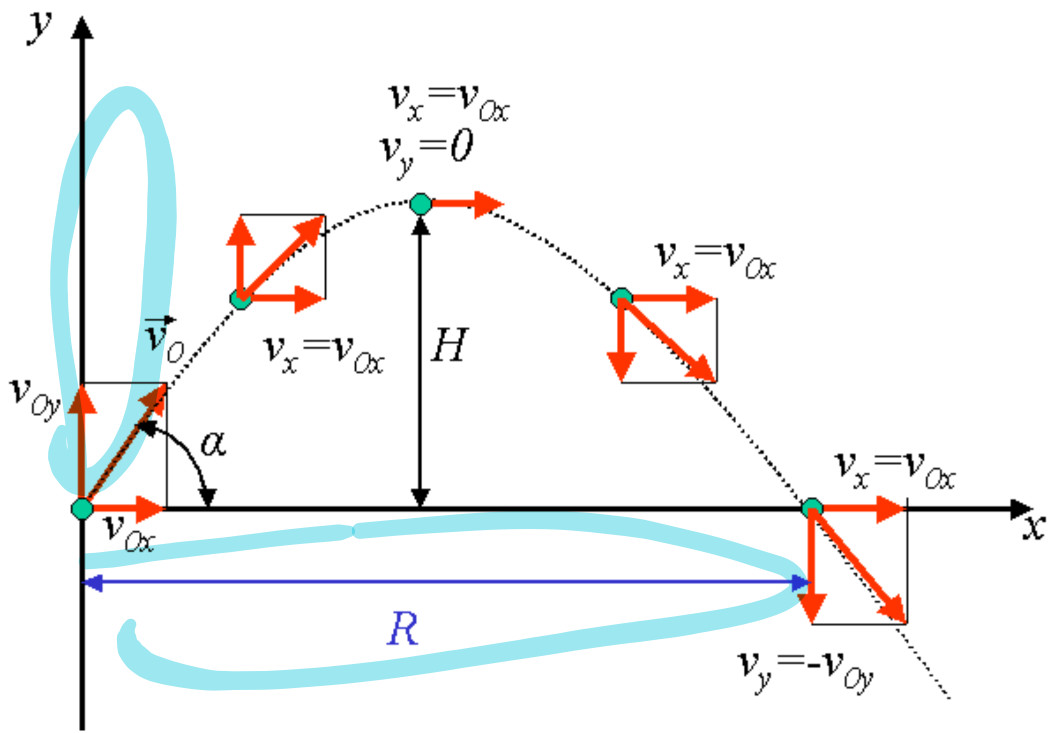
velocity $x = 0$

? velocity y = constant

$v_{fy} = v_i \sin - gt$

$0 = v_i \sin - gt$

$\frac{gt}{g} = \frac{v_i \sin\theta}{g} \rightarrow t = \frac{v_i \sin\theta}{g}$ ← half time ⇒ to prove the half time.



y
$v_x = v_{0x}$
$v_y = 0$
$\vec{v}_0$
$v_x = v_{0x}$
H
$v_x = v_{0x}$
v_{0y}
α
$v_x = v_{0x}$
x
v_{0x}
R
$v_y = -v_{0y}$

RANGE is the horizontal displacement of the projectile (dx)

MAXIMUM HEIGHT is the vertical displacement of the projectile (dy)

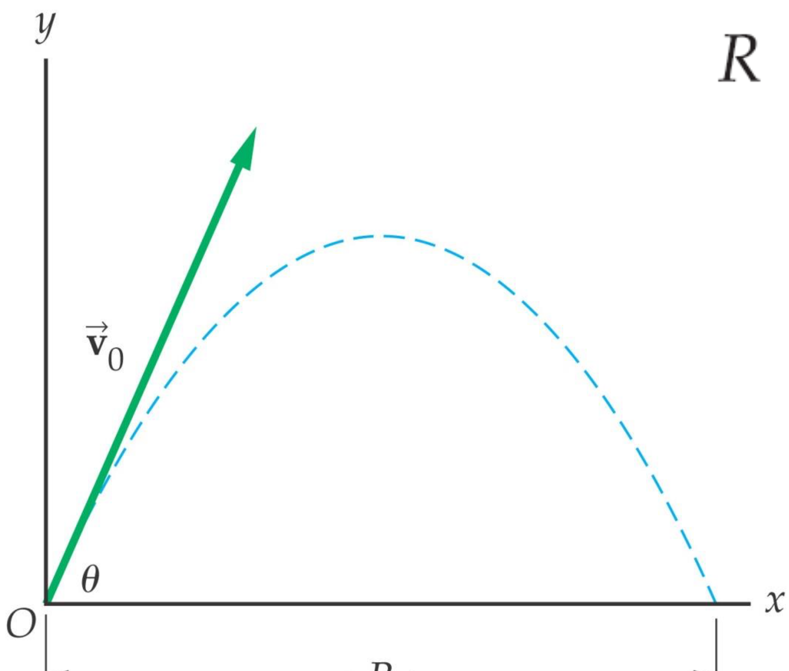
4-5 -Projectile Motion: Key Characteristics

•**Range**: the horizontal distance a projectile travels

•If the initial and final elevation are the same:

•Range of projectile launched from origin with an initial speed v0 and a launch angle θ is

$$R = \left(\frac{v_0{}^2}{g}\right)\sin 2\theta$$



) T_{total} : $\dfrac{2v_i \sin\theta}{\frac{1}{2}g}$

) T_{half} : $\dfrac{v_i \sin\theta}{\frac{1}{2}g}$

2

) Range : $x_f = 0 + (v_i \cos\theta)\,\dfrac{2v_i \sin\theta}{g}$

or

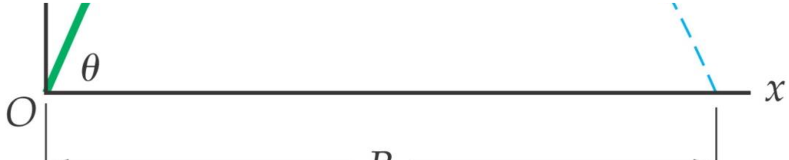
3 $x_f = \dfrac{v_i^{2} \sin\theta}{g}$

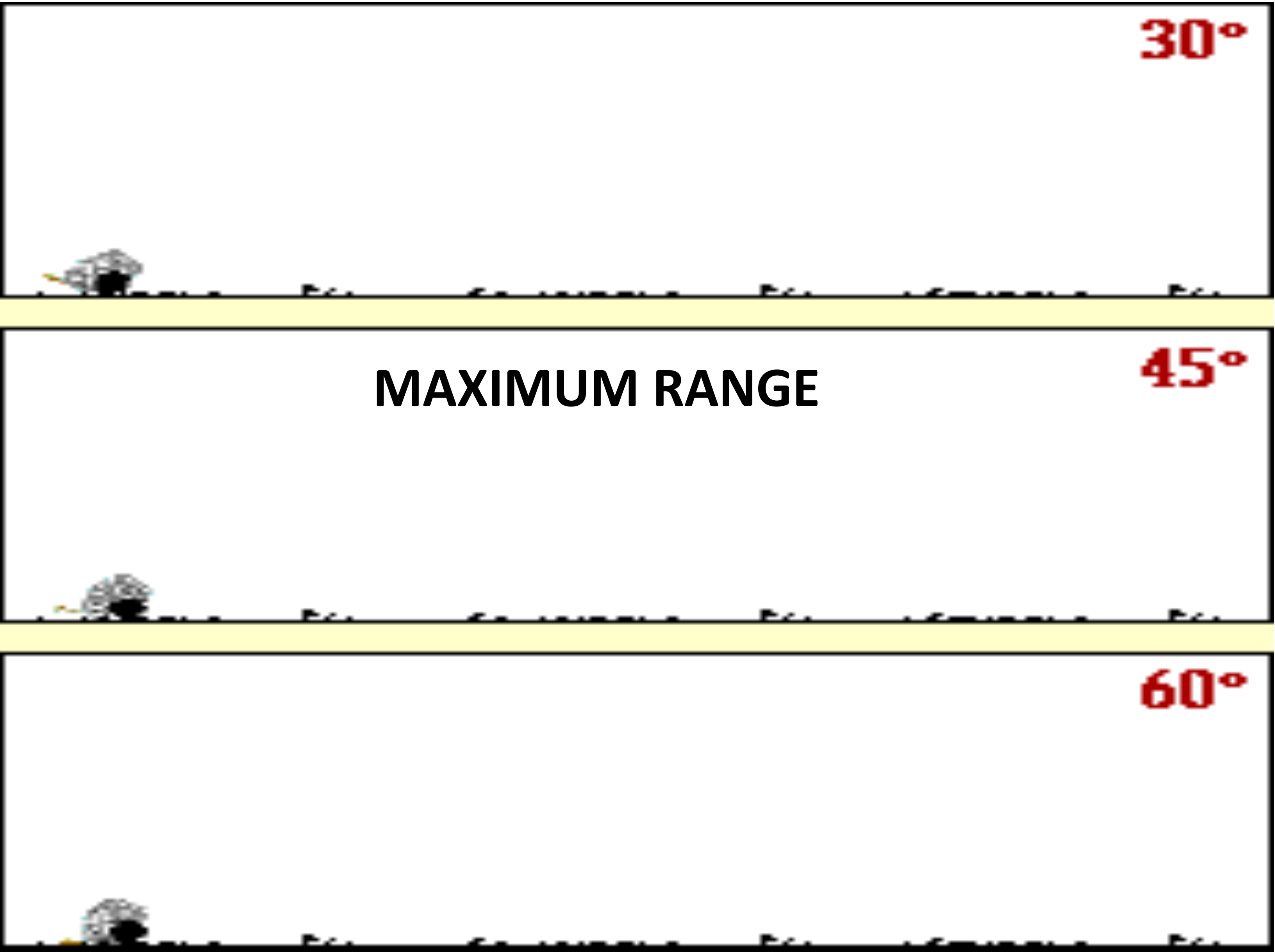
) y_{max} : $\dfrac{v_i \sin\theta^{2}}{2g}$

max

4 height

or

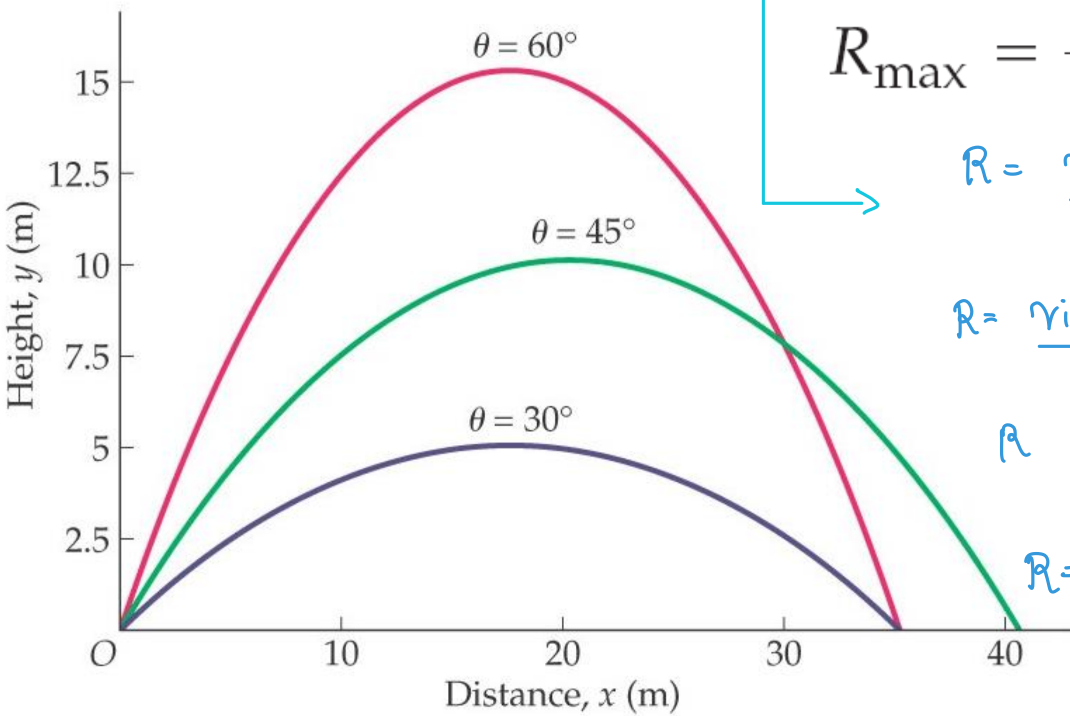



30°
45°
MAXIMUM RANGE
60°

4-5 -Projectile Motion: Key Characteristics

The range is a maximum when ϑ = 45°:

Donb memorize, just explaining



$$R_{max} = \frac{v_0{}^2}{g}$$

$$R = \frac{v_i{}^2 \sin 2\theta}{g}$$

$$R = \frac{v_i{}^2 \sin 2(45)}{g}$$

$$R = \frac{v_i{}^2 \sin 90}{g}$$

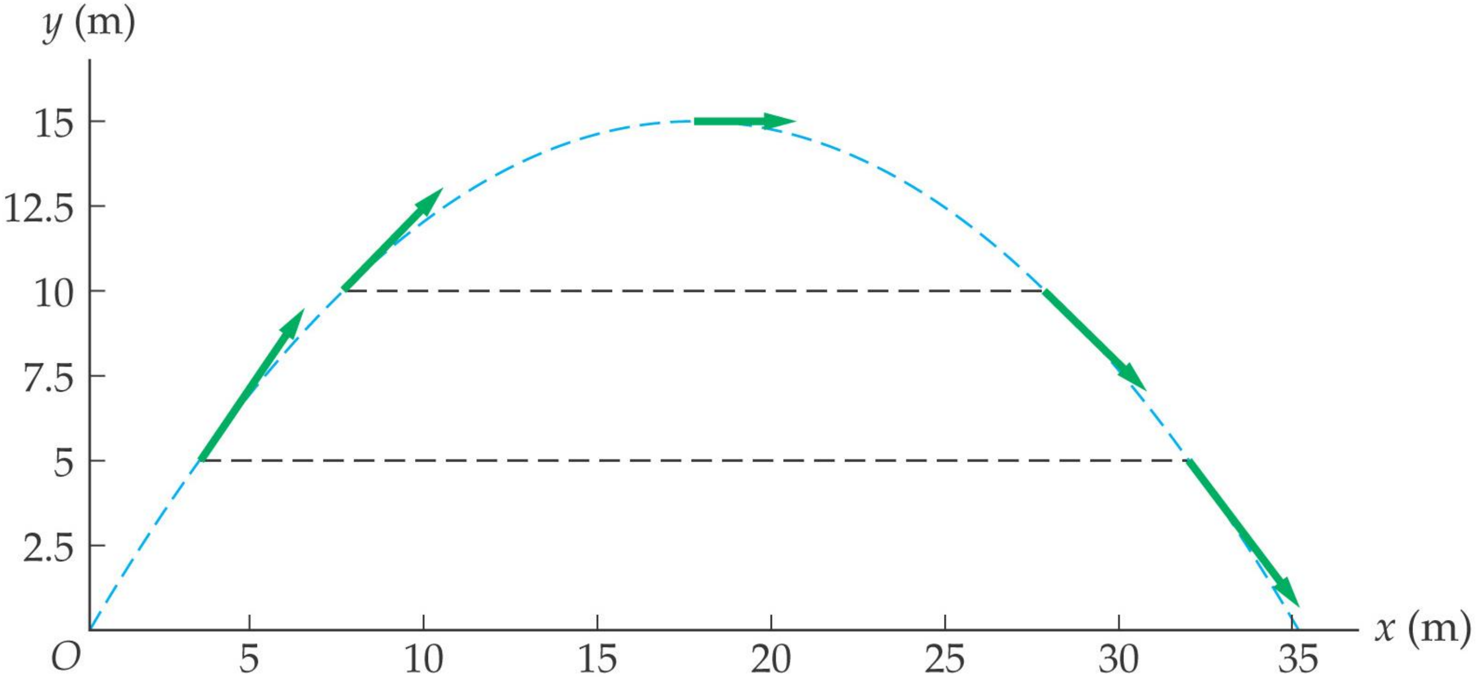
$$R = \frac{v_i{}^2}{g}$$

(b)

$x = \frac{1}{2} R \rightarrow (y\ max)$

4-5- Projectile Motion: Key Characteristics

Symmetry in projectile motion:



Time of flight

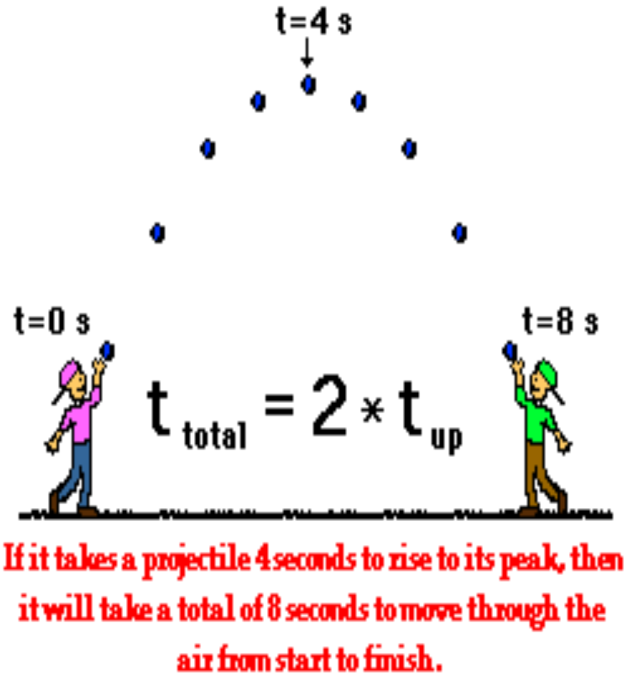
1-Time of Flight : The time taken by the projectile from when launched and when it lands is

$$t = (2\, v_o / g)\, \sin\theta$$

Time of flight

- **Determination of the Time of Flight**
- $t_{total} = T = 2vosin\theta/g$

- **Time at peak**
- $t_{half} = v_o \sin\theta/g$



Maximum height

- Maximum height of a projectile above its launch site is

$$y_{max} = (v_0 \sin\theta)^2 / 2g$$

where,

y_{max} = displacement (m)

θ = angle of projection (degrees)

V_0 ---initial speed in m/s

Problems

- **Question 1:** A body is projected and landed at the same level with a velocity of 20 ms^{-1} at 50^o to the horizontal. Find
-

  (i) Maximum height reached------ **Ans.= 11.97 m.**
  (ii) Time of flight and------- **Ans.= 3.126 s.**
  (iii) Range of the projectile-------- **Ans.= 40.196 m.**

- **Question 2:** John is on top of the building and jack is down. If john throws a ball at an angle of 60^o and with initial velocity 20 m/s. At what height will the ball reach after 2 s?

- **Vertical distance, $y = V_{oy}\, t - 1/2\, gt^2$**
- **Ans.= 15.04 m**

Problems

- **Question 1:** A body is projected and landed at the same level with a velocity of 20 ms^{-1} at 50° to the horizontal. Find
-

  (i) Maximum height reached------ **Ans.= 11.97 m.**

Total time ← (ii) Time of flight and------- **Ans.= 3.126 s.**

Special case

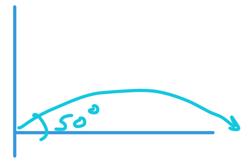
General launch:

$x_i = y_i = 0$

$v_{ix} = v_i \cos\theta$

$v_{iy} = v_i \sin\theta$

$- = 0$



$v_i = 20\ m/s$

(i): Max H: $\dfrac{(v_i \sin\theta)^2}{2g}$

$= \dfrac{(20 \sin 50)^2}{2(9.81)} = 12\ m$

(ii): Total: $\dfrac{2 v_i \sin\theta}{g}$

$= \dfrac{2(20 \sin 50)}{9.81} = 3.1\ s$

(iii): Range: $\dfrac{v_i^2 \sin 2\theta}{g}$

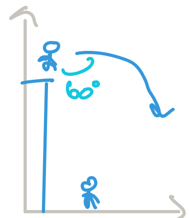
$= \dfrac{20^2 \sin(2 \times 50)}{9.81} = 40\ m$

- **Ans.= 15.04 m**

Problems

- **Question 2:** John is on top of the building and jack is down. If john throws a ball at an angle of 60° and with initial velocity 20 m/s. At what height will the ball reach after 2 s?

city



$V_i = 20$ m/s

$t = 2.0$ s

General launch:

$x_i = y_i = 0$

$v_{ix} = v_i \cos\theta$

$v_{iy} = v_i \sin\theta$

- **Vertical distance, $y = V_{oy}\, t - 1/2\, gt^2$**

eg o y = , sin -- $-\frac{1}{2}$ g

H · h 60 $P = (20 \sin 60) 2 - (\frac{1}{2} \times 9.81 \times 2^2)$

= 15

- **Ans.= 15.04 m**

2D (x, y)

Curved → projectile : $a_x = 0$, $a_y = -g$

General launch :

$x_i = y_i = 0$

$v_{ix} = \cos\theta$

$v_{iy} = \sin\theta$

$y_f = 0$

in text book

Solved

Example-4-5

- Chipping from the rough,a golfer sends a ball over a 3m high tree that is 14m away. The ball lands at the same level from which it was struck after traveling a horizontal distance of 17.8m-on green of course.
- (a) if the ball left the club 54.0 above the horizontal and landed on the green 2.24s later, what was its initial speed?
- (b)How high was the ball when it passed over the tree?

$v_i \cos\theta$

$\cancel{x_f = x_i} + v_i\, x\, t \rightarrow t \quad v_i = \frac{17.8}{\cos(54)\times 2.24} = 13.5\ m/s$

$\cancel{\theta}\ t$

$v_i \times 6$

$v_i \sin\theta$

$= \cancel{y_i} + \cancel{v_{iy}}\, t - \frac{1}{2} g t^2$

cos

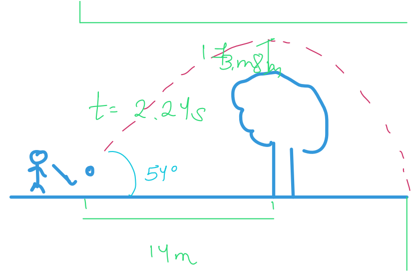
$= v_i \cos\theta\, t \rightarrow t = \frac{x_f}{v_i \cos\theta} = \frac{14}{13.5} = 1.76\ s$

yf

$y_f = (13.5)\sin 54 \cdot 1.76 - \frac{1}{2}(9.81)\times 1.76^2 = 2$

xf

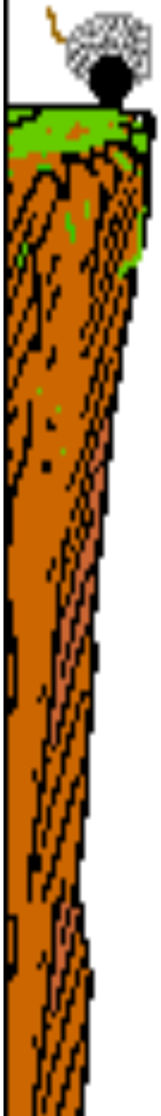
the tree?



PROJECTILE I

zero
launch

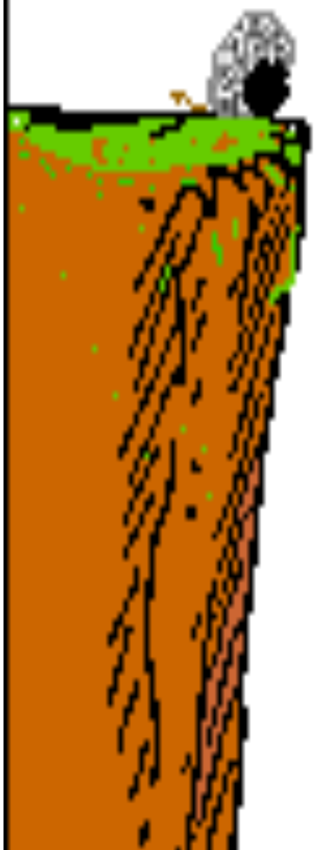
(SIMPLE PROJECTILE)



$t = \ -- \ s$

$v_x = \ -- \ m/s \qquad v_y = \ -- \ m/s$

PROJECTILE II (WITH ANGLE)



$t = $ -- s

$v_x = $ -- m/s $v_y = $ -- m/s

Summary of Chapter 4

- Components of motion in the *x*- and *y*-directions can be treated independently
- In projectile motion, the acceleration is $-g$
- If the launch angle is zero, the initial velocity has only an *x*-component
- The path followed by a projectile is a parabola
- The range is the horizontal distance the projectile travels