A-LEVEL PHYSICS

CHAPTER 2

ON THE MOVE

Objectives

You should understand:

1. Displacement, speed, velocity, acceleration.
2. Calculation of average and instantaneous speeds and velocities.
3. Representation by graphical methods of uniform and nonuniform acceleration.
4. Significance of areas of velocity -time and acceleration-time graphs and gradients of displacement-time and velocity-time graphs for uniform and non-uniform acceleration e.g. graphs for motion of bouncing ball.
5. Equations for uniform acceleration
6. Acceleration due to gravity, g Independent effect of motion in horizontal and vertical directions of a uniform gravitational field. Problems will be solvable using the equations of uniform acceleration.
7. Qualitative treatment of friction.
8. Qualitative treatment of lift and drag forces.
9. Terminal speed.
10. Knowledge that air resistance increases with speed.
11. Qualitative understanding of the effect of air resistance on the trajectory of a projectile and on the factors that affect the maximum speed of a vehicle.

2.1 Speed and velocity

1. **Speed is defined as change of distance per unit time.** scalar, has magnitude only

- For an object moving at constant speed:

$$v = \frac{\text{distance travelled}}{\text{time taken}} = \frac{d}{t}$$

- For an object moving at changing speed,
  average speed

$$\bar{v} = \frac{\text{total distance travelled}}{\text{total timetaken}}$$

instantaneous speed

$$v = \frac{\Delta d}{\Delta t}$$

- In a distance-time graph: speed of the object = gradient of the line.

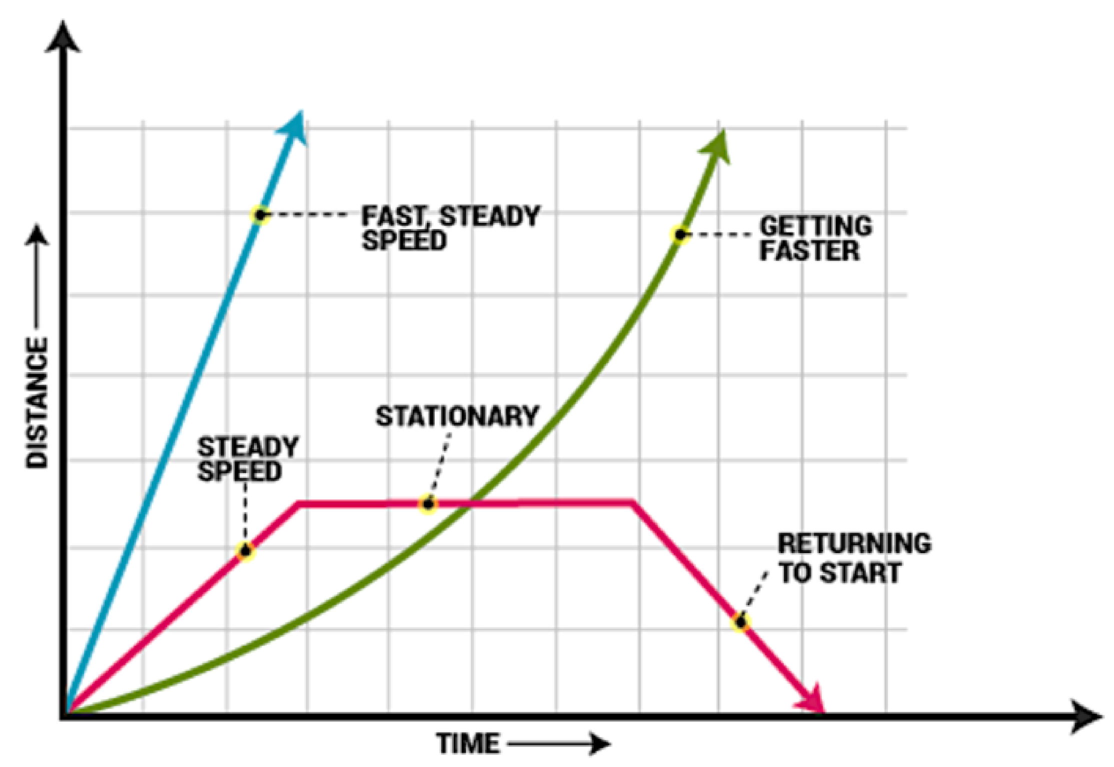

Figure 1: Some examples of distance-time graphs.

2. **Velocity is defined as change of displacement per unit time.** vector, has magnitude and direction.

- An object moving at constant velocity moves at the same speed without changing its direction of motion.
- In a displacement-time graphs: velocity of the object = gradient of the line.

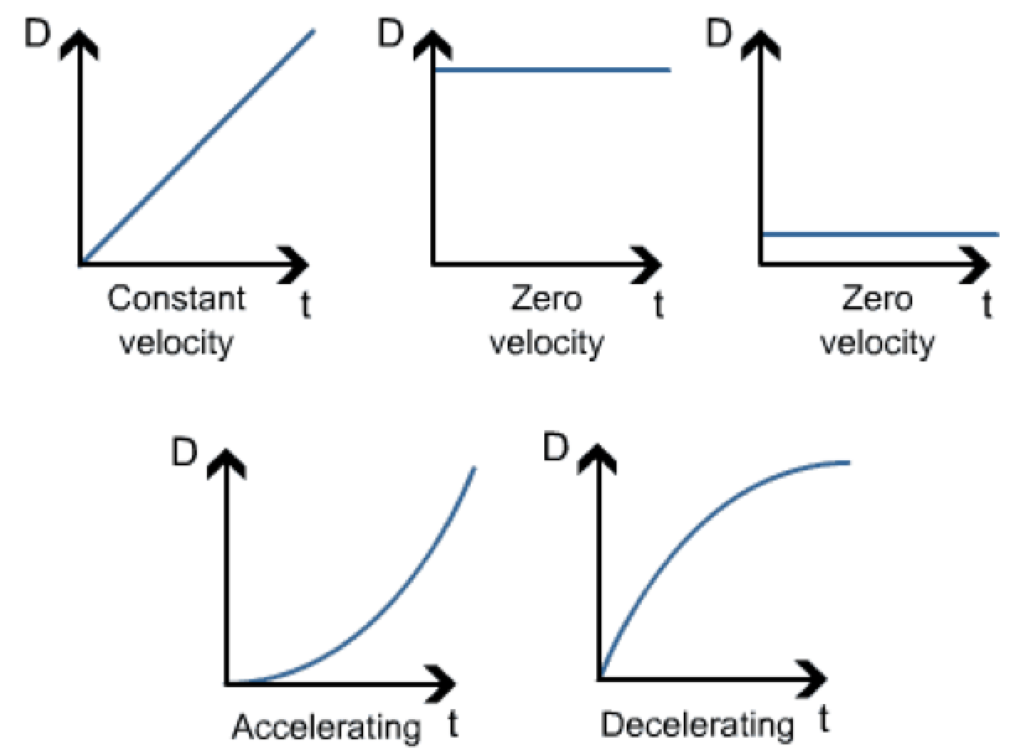

Figure 2: Some examples of displacement-time graphs.

- In one-dimensional motion, specifying directions with a plus or minus sign is important.

2.2 Acceleration

1. Acceleration is defined as change of velocity per unit time. Acceleration is a vector quantity and measured in meter per second per second (ms^{-2}). vector, has magnitude and direction.

- For uniform acceleration:

$$a = \frac{\text{change of velocity}}{\text{time taken}} = \frac{v - u}{t}$$

.

- For non-uniform acceleration, a = gradient of the line on the velocity-time graph.

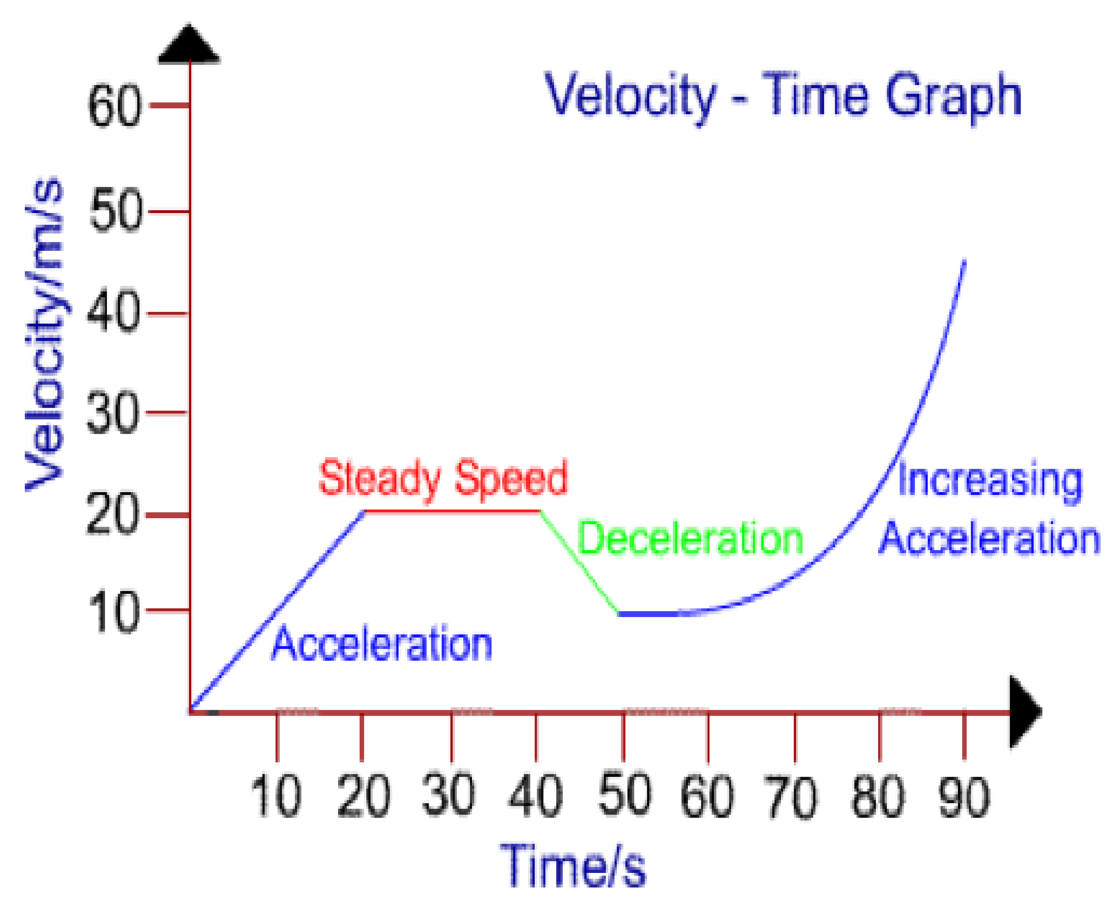

Figure 3: Experimental setup for investigating free fall.

2.3 Motion along a straight line at constant acceleration

1. Equations of motion (suvat)

$$v = u + at \quad (1)$$

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

$$s = ut + \frac{1}{2}at^2 \quad (3)$$

$$2as = v^2 - u^2 \quad (4)$$

2. In a velocity-time graph: displacement = area under the line of a velocity-time graph.

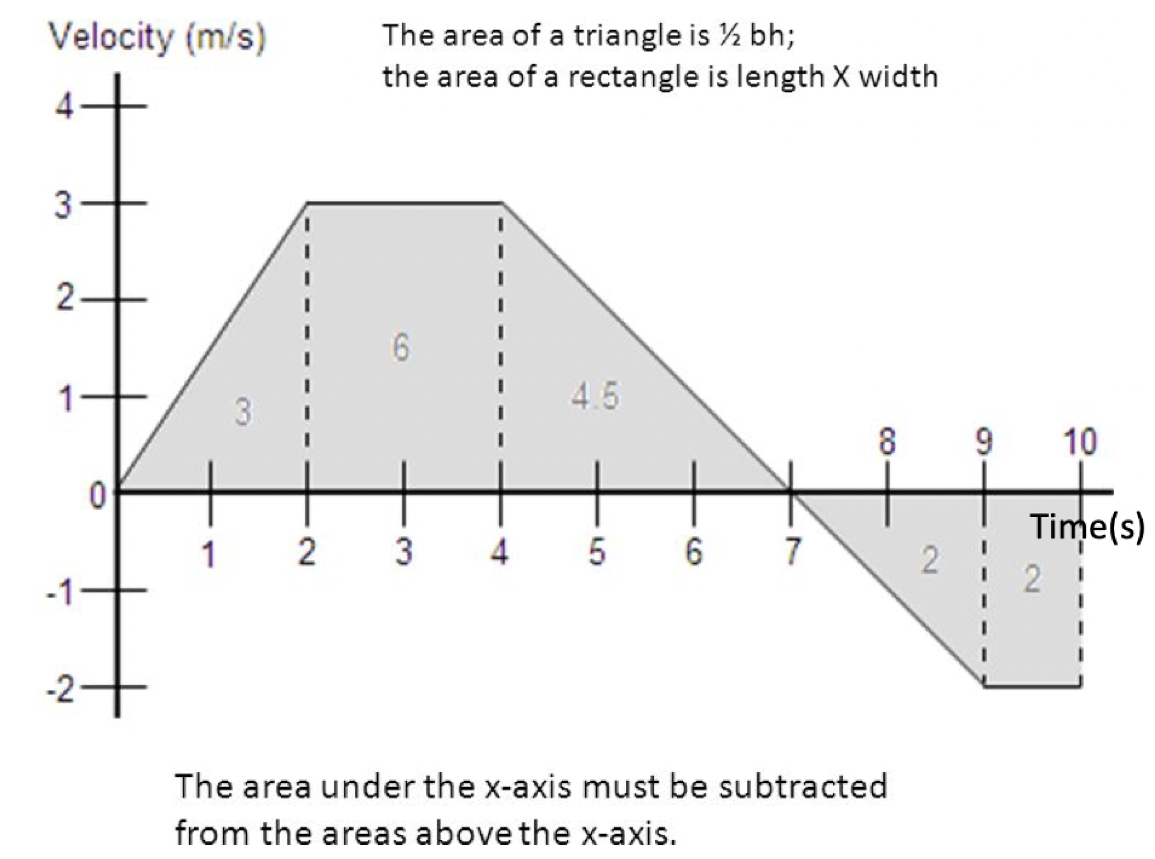

Figure 4: Find displacement from a velocity-time graph.

2.4 Free fall

1. An object is in free fall if the only force acting on it is gravity. So a falling object can only be in free fall if there is **no air resistance**.

- The acceleration does not depend upon the mass of the object.
- The acceleration due to gravity g, on Earth is treated as a constant. Accurate measurements show that $\mathbf{g = 9.8ms^{-2}}$
- The acceleration varies slight from place to place. It decreases as you go further away from the center of the Earth.

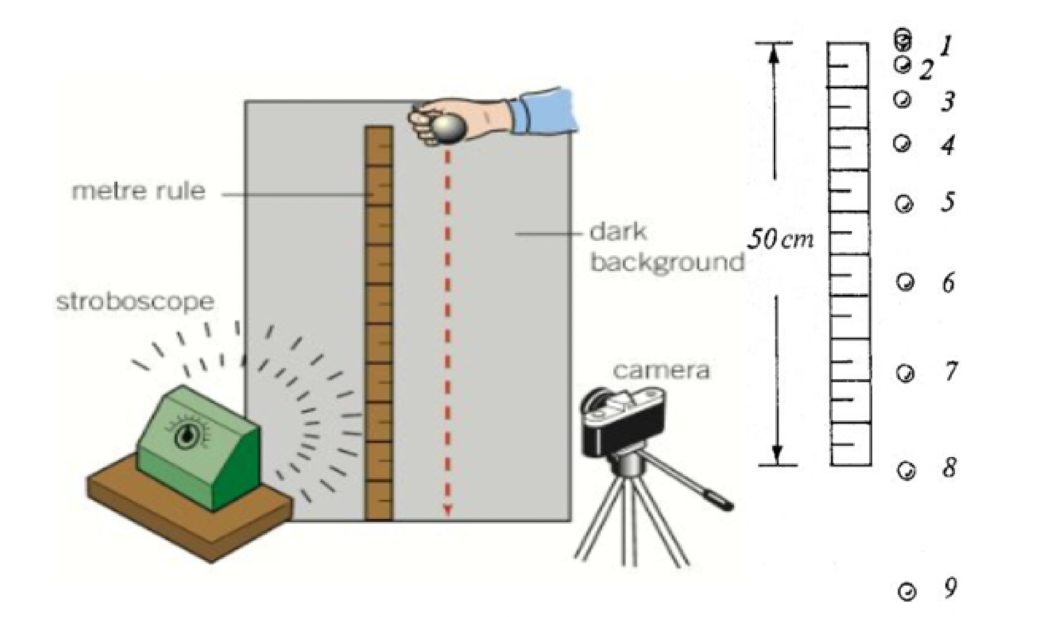

Figure 5: Experimental setup for investigating free fall.

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Find g through an experiment

The flashing light flashes at a known constant rate. A vertical meter rule is used to provide a scale. A small steel ball feels very little air resistance. A multi-flash photo of the ball's flight is made. For each image of the ball on the photograph, the time of descent of the ball and the distance fallen can be measured.
The initial velocity, u is zero. We have $s = \frac{1}{2}\, g\, t^2$. Plotting s against t^2 gives a straight line through the origin (since intercept c = 0). The gradient, m, of the straight line must be $\frac{1}{2}\, g$.

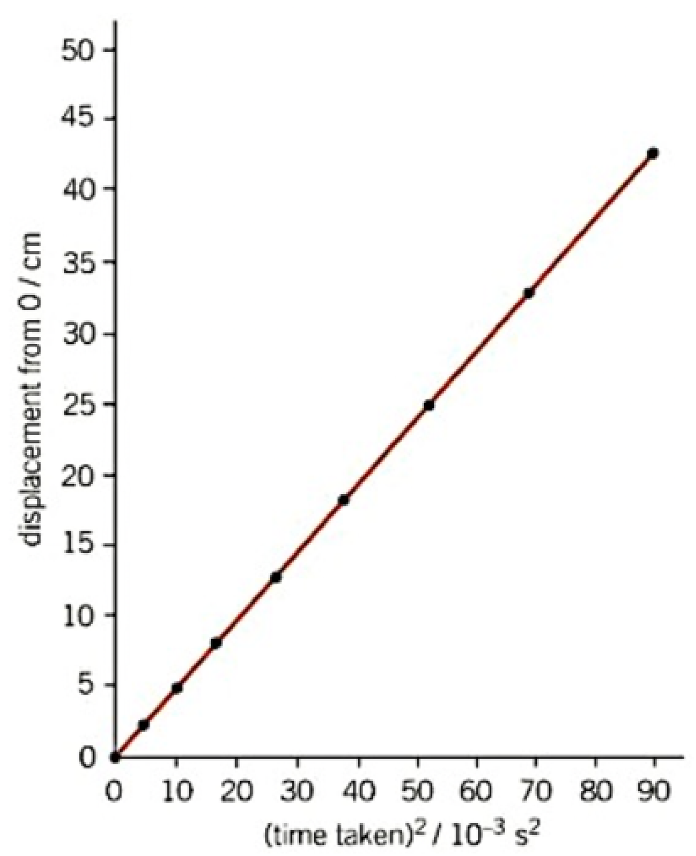


Figure 6: A graph of a against t^2.

2.7 Projectile motion 1

1. A projectile is any object projected into the air and **acted upon only by the force of gravity and air resistance**.

- The gravity gives a downwards acceleration only and there is no acceleration in the horizontal direction.
- The horizontal velocity remains constant.
- The horizontal and vertical motions of an object are independent and can be treated separately in calculations.

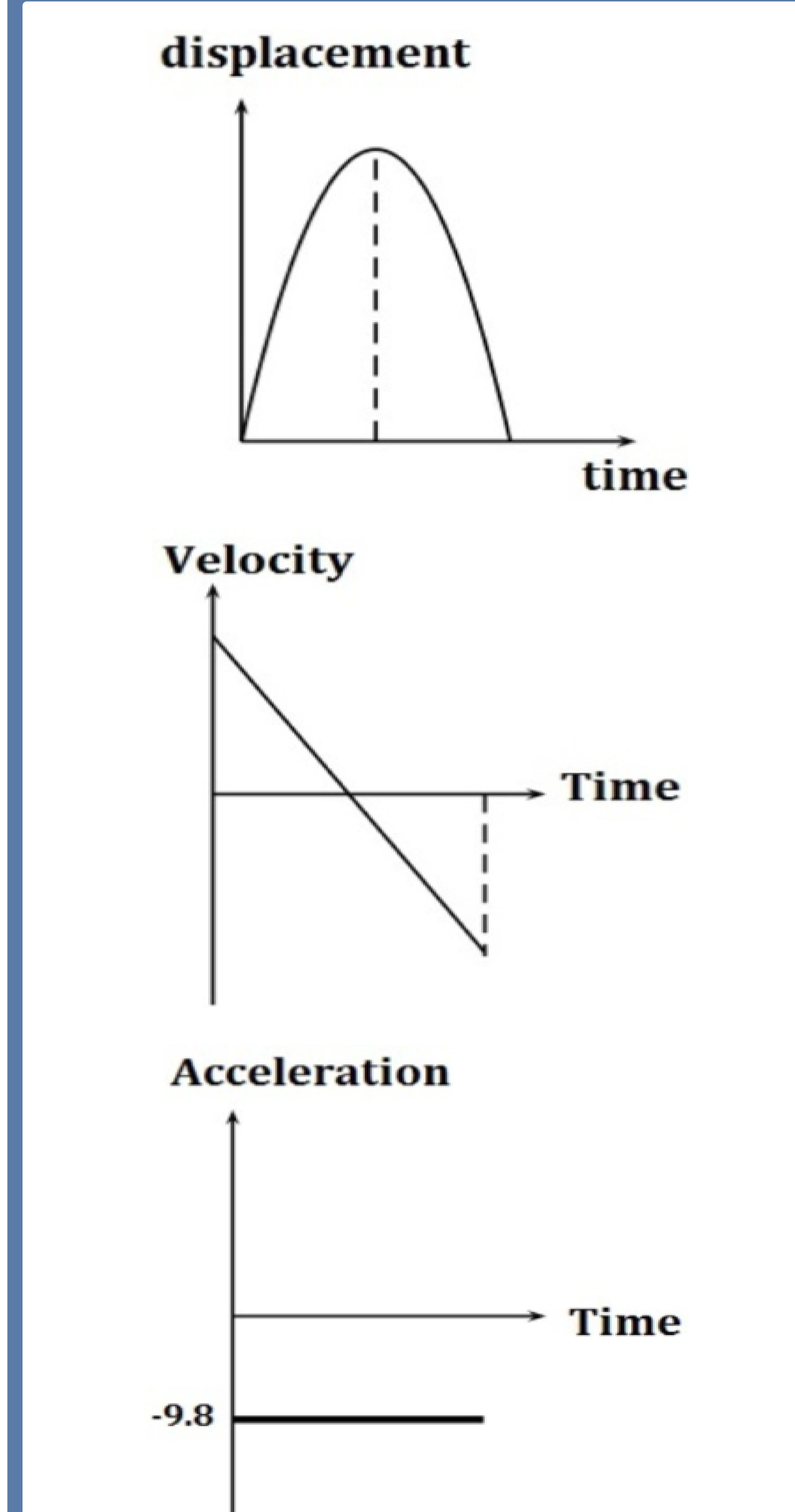
2. Vertical projection

- For an object moves vertically and have **no horizontal motion**, it experiences a vertical projection. Its displacement, y, and velocity, v, after time t are given by

$$v = u - gt$$
$$y = ut - \frac{1}{2}gt^2$$

where u is its initial velocity in the upward direction.

Motion graphs in a vertical projection



3. Horizontal projection

- For a projectile does have a horizontal motion but **no initial vertical velocity**, it experiences a horizontal projection. If its initial velocity is U, then at time t after projection:
- The horizontal component of its displacement ,

$$x = Ut$$

- The vertical component of its displacement,

$$y = \frac{1}{2}gt^2$$

.

- The horizontal component of its velocity

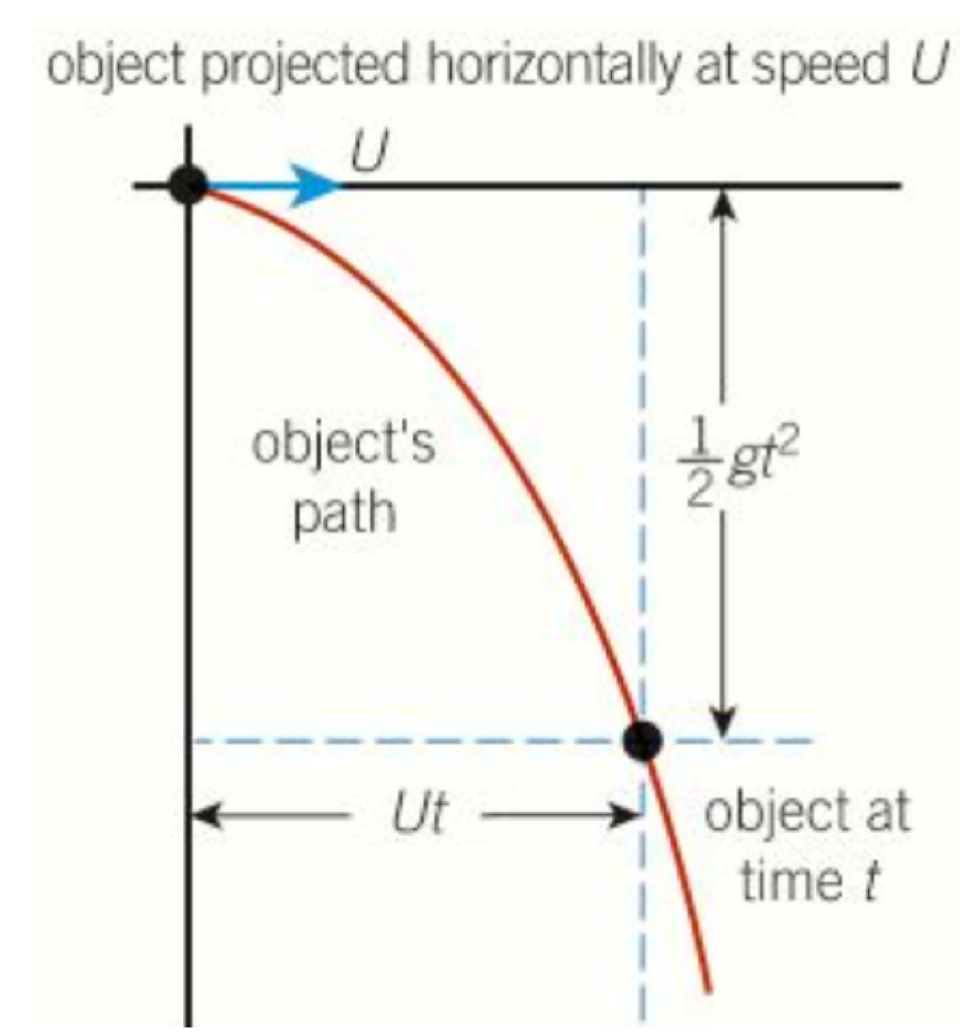
$$v_x = U$$

and a vertical component

$$v_y = -gt$$

.

- The speed is $\sqrt{v_x^2 + v_y^2}$



2.8 Projectile motion 2

1. Any form of motion where an object experiences **a constant acceleration in a different direction to its velocity** will be like a projectile motion.

- The object moves in a bilaterally symmetrical, **parabolic** path because the vertical position of the object is influenced only by a constant acceleration, (if constant drag etc. is also assumed) and also because horizontal velocity is generally constant.

2. The effects of air resistance

- The **drag force** is due to air resistance, partly caused by friction with the air. It acts in the opposite direction to the direction of motion and **increases with the speed** of the projectile.
  In the horizontal direction: both horizontal speed and its range would be reduced.
  In the vertical direction: drag would reduce the maximum height and makes its decent steeper than its ascend.
- The **lift force** is generated due to the pressure difference between the top of the object and the bottom. The lift is perpendicular to the surface.
- **Terminal velocity** is the maximum velocity attainable by an object as it falls through a fluid. It occurs when the air resistance is equal to the downward force of gravity (FG) acting on the object.

3. Angled projection: when a ball is thrown at a velocity u at an angle to the ground:

- The horizontal velocity component $\mathbf{v_x = u\cos\theta}$
- The vertical velocity component $\mathbf{v_y = u\sin\theta - gt}$
- The horizontal displacement component $\mathbf{x = vt\cos\theta}$
- The vertical displacement component $\mathbf{y = vt\sin\theta - \frac{1}{2}gt^2}$

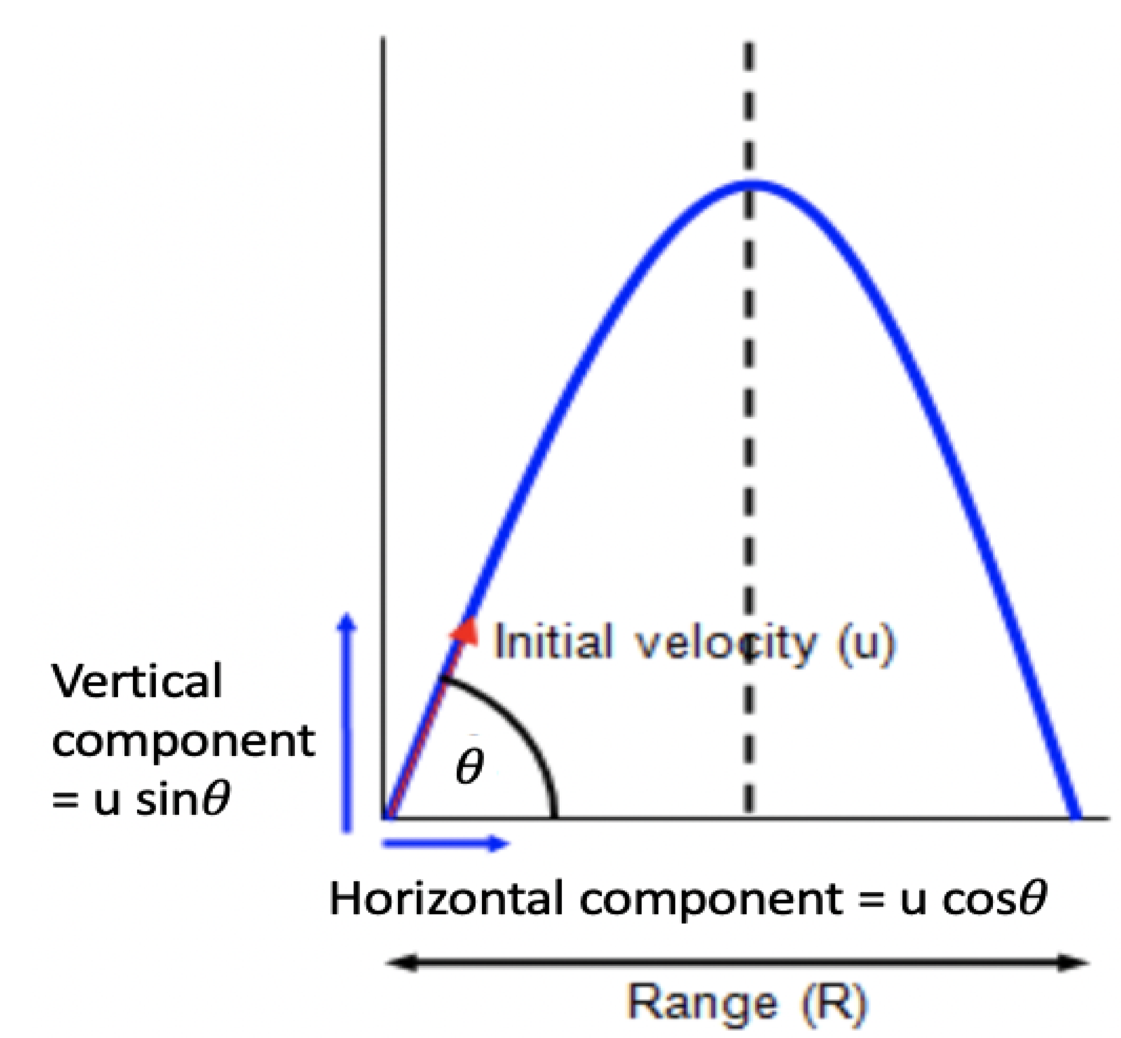


Figure 7: Angled projection.