Module 17 (Experimental)

1. Measuring Terminal velocity

When an object is dropped in a gravitational field, it will accelerate downwards at a rate of 9.8 m/s^2, never slowing down. But if we drop the same object with air resistance present, then it will encounter an opposing force due to air resistance which will be directly proportional to the velocity:

$$F = -bv$$

where b = coefficient of damping

As the object picks up speed, the force due to air resistance will increase, until it becomes equal to the force due to gravity. Beyond this point, there is no net force acting on the body and so the body will fall down at a constant velocity. This velocity is called the "terminal velocity" (v_t) of the object and is given by:

$$F = mg = bv_t \Rightarrow v_t = \frac{mg}{b}$$

The terminal velocity can be defined in a more general way also. When an object is moving under the influence of an arbitrary set of forces and the forces reach equilibrium after a certain period of time, the final velocity achieved by the object is its terminal velocity.

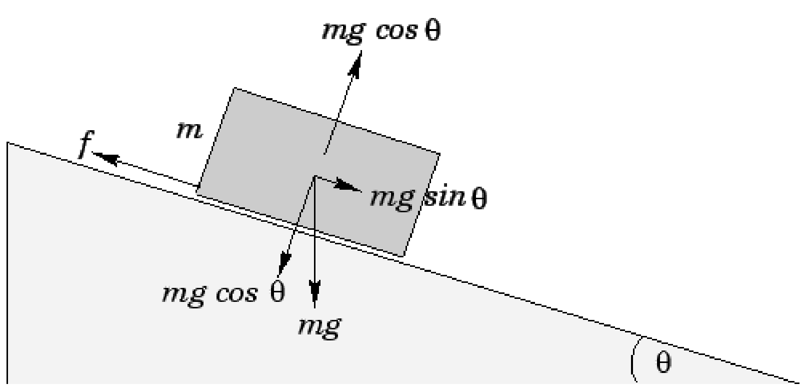
TASKS:

- Think of 3 different experiments you can perform in the lab to measure the terminal velocity of an object. Also explain the possible sources of error in your proposed experiment.
- Can you use your mobile phone to measure the terminal velocity of a falling object?
- Imagine an object is moving down a ramp with friction and air resistance is also present. What will be the formula for the terminal velocity in this scenario?

2. Using the law of conservation of energy to find out the coefficient of kinetic friction

When an object slides down a ramp from a height H to a height h ($h < H$), it loses potential energy and gains kinetic energy. Since gravity is a conservative force, the total energy is conserved, such that the loss in potential energy is exactly compensated for by an increase in kinetic energy.

But if the ramp has friction, then some of the energy will be lost. You will work on an experiment in which you will use this discrepancy in energy to find out the coefficient of kinetic friction of the ramp.



TASKS:

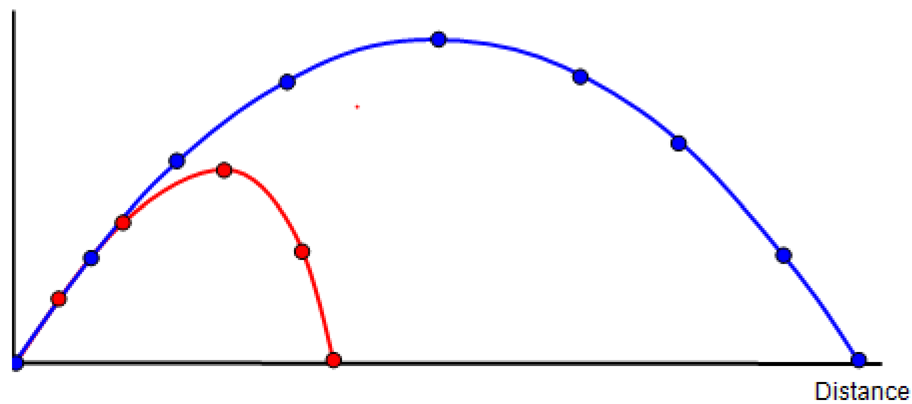
- Derive a formula for the coefficient of kinetic friction (μ_k) of the ramp in the above scenario.
- If you are performing an experiment to calculate μ_k, what are the relevant experimental variables that you will need to measure?
- Explain some possible sources of error in this experiment.
- Using error analysis, derive a formula for the relative error in μ_k

3. Measuring the damping coefficient of air in projectile motion

When an object is thrown in the air with a speed v_0 at an angle θ from the horizontal, it traces a parabolic path with the range R given by the familiar formula:

$$R = \frac{v_0^2 \sin 2\theta}{g}$$

If we introduce air resistance, then the motion will change (as shown in the figure below) and the range of the projectile will be less than before.



We will perform an experiment in which we will use the formula for the range of a projectile (in the presence of air resistance) to find out the damping coefficient (b) of air.

TASKS:

- Assuming a linear damping force ($F_{air} \propto v$), derive a formula for the range of a projectile. Assume the object has mass m, initial velocity v_0, angle of launch θ and the damping coefficient of air is b.
- Can you devise an experiment in which you can use the above formula to find out 'b'?
- Discuss the possible sources of error in your proposed experiment.
- Derive the expression for the relative error in the range R.

4. Balancing forces on a force table

Force is a vector, meaning that it has both a magnitude and a direction. For a body to be in translational equilibrium, the vector sum of all the forces acting on it must equal zero. This means that not only the magnitudes but also the directions of the forces must be such that they cancel each other out.

In this experiment, the trainees will use a force table (built in-house) to understand the concept of translational equilibrium. You will be tasked with finding the appropriate configurations (weights and angles) to achieve equilibrium for a given set of masses.

TASKS:

- If the masses are all equal, then the angles between them will be equal. Derive a formula for this angle if the number of masses is 'n'.
- If the masses are different then they will not be placed at equal angles with respect to each other. Assume we have 3 masses and one of them is twice the other two. What will be the angles between each of the masses when they are in equilibrium?
- What are some possible sources of error in this experiment?

5. Investigating the physics of a gyroscope

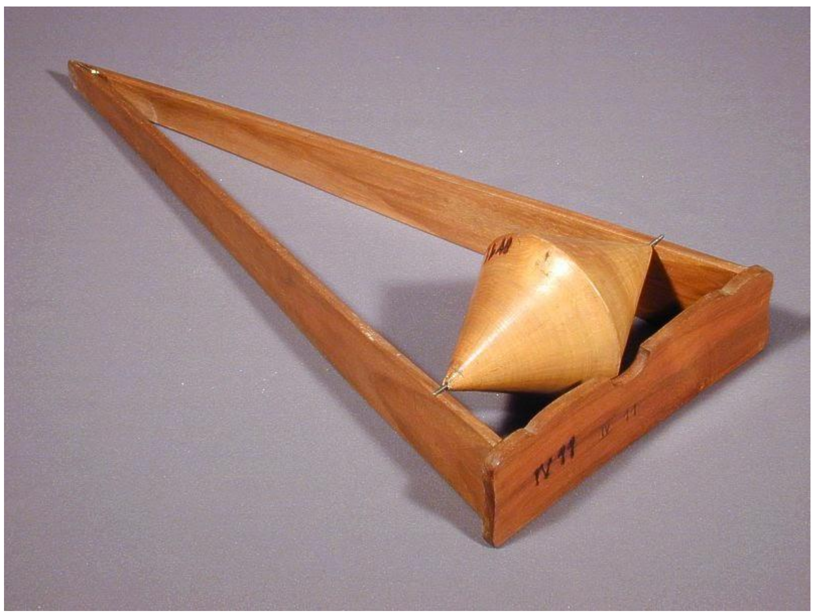
A gyroscope works on the principle of angular momentum conservation and is widely used in technology and industry. Since angular momentum is a vector, conservation of this quantity entails that the direction must also be preserved. This is why a gyroscope (if it is spinning fast enough) can resist perturbations to its axis of rotation and keep itself upright.

TASKS:

- Demonstrate conservation of angular momentum using a bicycle-wheel gyroscope and a small hand-held gyroscope
- Think of 2 or 3 other experiments that can be used to demonstrate the conservation of angular momentum.

6. Explaining the physics of the "antigravity" double-cone

It is possible to devise a double cone-shaped bottle that rolls "up" a downward facing ramp. You will see a demonstration of this in the lab.

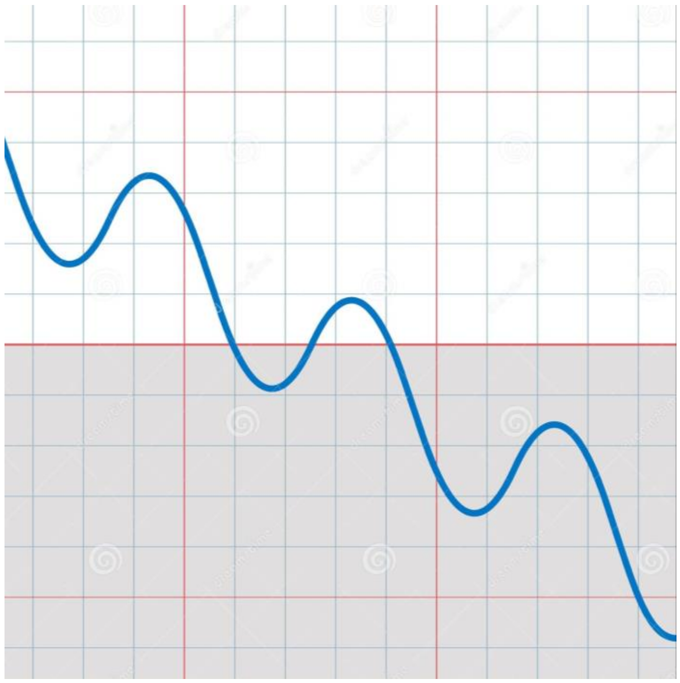


TASKS:

- Explain the physics behind the apparent "anti-gravitational" motion of the double cone.
- What conditions are required to be met in order to yield this strange effect? Give your answer in terms of the dimensions of the cone and the ramp.
- Does this effect depend on the mass of the cone?
- If the ramp is assumed frictionless, find out the final velocity of the cone when it reaches the end of its journey. Assume the mass of the cone is 'M', its tip-to-tip length is 'H', its radius of cross-section at the middle is 'R', the initial height is 'h_1', the final height is 'h_2' and the opening angle of the ramp is 'α'.

7. Calculating the traversal time of a ball along ramps of different shapes

In this experiment, we release a metal ball of fixed mass ‘m’ down ramps of different shapes. One of them is a straight ramp whereas the other is curved, containing multiple hills and valleys. Model this second ramp as a sinusoidal curve sloping downward, as shown in the figure below.



TASKS:

- Find the time of traversal of the ball through a straight ramp of length ‘L’ and angle ‘θ’ with respect to the horizontal. The ball starts with zero initial velocity. Assume no friction in the ramp.
- Now consider the curved ramp (as shown in the figure above). It is defined by the equation: $y = \sin x - \frac{x}{2}$. Assume the starting height is ‘H’, the total horizontal distance travelled is ‘D’ and the slope of the ramp at the starting position is ‘1’. The ball starts with zero initial velocity. Assume no friction in the ramp. Write down an expression for the time of traversal of the ball through the ramp (you can just write down the integral).
- What is the final velocity of the ball as it leaves the two ramps? If it is equal in both cases, then what explains the difference in the time of traversal in the two ramps?