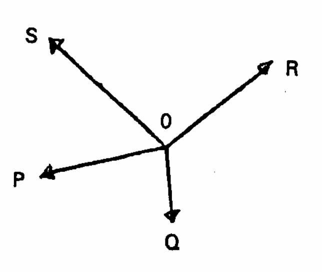
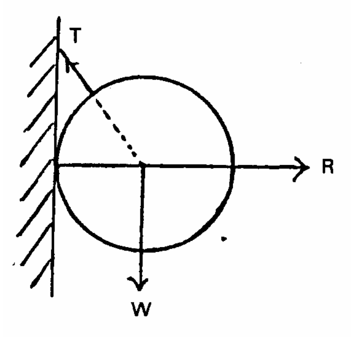
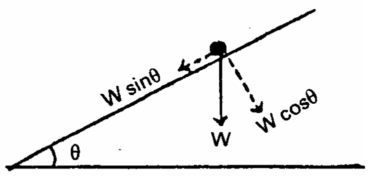
UNIT 2: Statics and Friction

Specific Objectives:

1. To understand the nature of forces, moments and couples.
2. To learn the resultant and resolution of a system of coplanar forces.
3. To understand the nature of frictional forces and the laws of friction.
4. To learn the conditions of equilibrium of particles and rigid bodies under a system of coplanar forces and to solve practical prob|ems involved.

Detailed Content	Time Ratio	Notes on Teaching
2.1 Forces, Resultant and Resolution of Forces	3	Fundamental knowledge of the vector nature of forces should have been come across in studying Secondary Physics At this stage, teachers should emphasize to students the following basic factors which determine the effect on a body to which a force is applied: (1) The magnitude of the applied force. (2) The line of action of the applied force, i.e. the direction and the point of application in which the force is applied. The idea of concurrent forces should be introduced. Two or more forces acting on a particle 0 and the forces acting on a sphere which is supported by a string on a smooth vertical wall and rests in contact with the wall are examples of concurrent forces.  

Detailed Content	Time Ratio	Notes on Teaching
		A system of forces can be reduced to a single resultant force. Students should be able to find the resultant of any two forces by the triangle law or parallelogram law. By successive application of either of the two laws, the resultant of a system of coplanar forces can be obtained. Knowledge of vector addition mentioned in Section 1.2 may be referred. Students are expected to know how to resolve a force into two components in any two directions, especially two mutually perpendicular components. Knowledge of resolution of vectors mentioned in section 1.5 may be referred. Examples like resolving the weight of an object on an inclined plane into two components along the directions parallel and perpendicular to the plane respectively are worth discussing.  The method of finding the resultant of a system of coplanar forces by resolving all forces into two mutually perpendicular components should also be emphasized and illustrated with examples.
2.2 Resultant of Parallel Forces, Moments and Couples	3	Students are expected to know how to find the resultant of two or more like/unlike parallel forces acting on a rigid body. The moments of forces about a point and the turning effect of a couple formed by two equal unlike parallel forces should be discussed Students should be aware that the moment of a couple about an axis is independent of the position of the axis so long as the axis is perpendicular to the plane in which the couple acts.

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		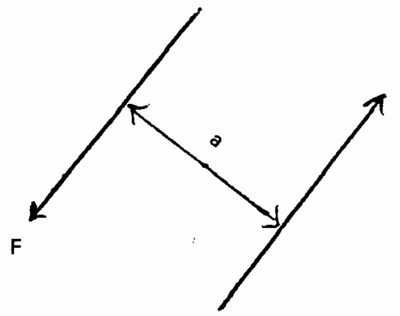
		The fact that the algebraic sum of the moments of two forces about any point in their plane is equal to the moment of their resultant force about the same point should be introduced. The underlying concept is then extended to the Principle of Moments (the algebraic sum of moments of any number of coplanar forces acting on a rigid body about any point in their plane is equal to the moment of their resultant about the same point).Students are also expected to make use of the above principle to reduce a system of coplanar forces to a single force or a couple. Determination of the centres of gravity of figures of regular shapes and uniform bodies is one of the applications of the Principle of Moments. Details may be referred to Unit 11.
		Example
		ABCDEF is a regular hexagon of side 2ℓ. Forces of magnitude 5N, 1N, 3N, 4N, 2N and 2N act respectively along the sides $\overrightarrow{AB}$, $\overrightarrow{BC}$, $\overrightarrow{CD}$, $\overrightarrow{DE}$, $\overrightarrow{EF}$ and $\overrightarrow{FA}$.

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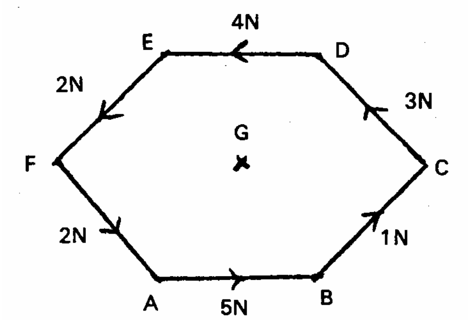
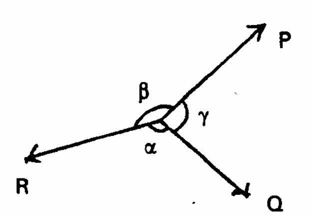
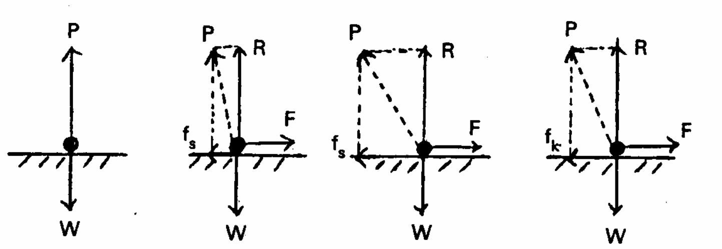
		
		In this example, students can be led to resolve the forces along and perpendicular to the direction AB and take moments about an axis through the centre of the hexagon, G. Students should be able to find that the system reduces to a couple.
2.3 Equilibrium of a System of Coplanar Forces		Knowledge of equilibrium of a system of coplanar forces should be made clear to students Teachers may first discuss with students the situation in which three concurrent forces are in equilibrium. The Lami's Theorem can then be introduced:
		 $\frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma}$

Detailed Content	Time Ratio	Notes on Teaching
		Sufficient exercises on applying the Lami's Theorem to solve three-force problems should be given. At this stage, students should be aware that a system of coplanar forces may either be (a)reduced to a single resultant force, (b) reduced to a couple, or (c) in equilibrium. Teachers should remind students that for a system of forces in R^2 to be in equilibrium, the following simultaneous conditions are satisfied and are helpful in solving the problem: (1) $\sum F_x = 0$, $\sum F_y = 0$ and (2) $\sum M_p = 0$ where F_x , F_y are component forces in R^2 and M_p am their respective moments about any point P.
Nature of Friction (a) Laws of friction	2	Students are expected to know that when a body moves or tends to move on a surface, friction always exists and it tends to prevent the body from moving. Two different types of friction should be distinguished, namely, the static friction and the kinetic friction. The former refers to the frictional force acting on a body which remains static (but it tends to move), while the latter refers to the frictional force acting on a moving body. The law of static friction and the law of kinetic friction should be stated and students are expected to know that the coefficient of static friction, μ_s is greater than the coefficient of kinetic friction, μ_k. Teachers should emphasize that the relationship between friction f and normal reaction R is $f \leq \mu_s R$, and $f = \mu_s R$ only when a limiting equilibrium is reached. The following figures may be helpful to illustrate this concept. (In the figure, P is the resultant of frictional force and normal reaction.)

Detailed Content	Time Ratio	Notes on Teaching



(a) (b) No motion $f_s < \mu_s R$ (c) Limiting equilibrium, motion impends $f_s = \mu_s R$ (d) Motion exists $f_k = \mu_k R < \mu_s R$

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		It is worthwhile at this stage to remind students the following points (1) The value of static friction is Independent of the areas and the shapes of the surfaces in contact provided the normal reaction is unaltered. (2) The value of kinetic friction is independent of the velocity of the object and is equal to $\mu_k R$. (3) The value of kinetic friction is slightly less than the limiting (static) friction.
(b) Angle of friction		Teachers should Introduce to students the term ' angle of friction (λ) ' and its relation with the static coefficient of friction: $\tan\lambda = \mu_s$. Examples such as finding the least force required to move a particle of weight W up a plane with angle of inclination smaller than the angle of friction may be introduced.
2.5 **Equilibrium of Rigid Bodies**	12	At this stage, students should be familiar with the following simultaneous conditions of an equilibrium system:

Detailed Content	Time Ratio	Notes on Teaching

(1) The resultant force of the system is zero.

(2) The resultant moment of the system about any point is zero.

Students are expected to be able to make use of the above two conditions and the laws of friction to set up independent equations and inequalities from a given physical situation. Students are also expected to know that condition (1) alone is sufficient for showing a system of concurrent forces to be in equilibrium.

In tackling problems, care should be taken to determine the directions and positions of the reactions on bodies. Although the position of a reaction is usually at the point of contact, teachers should remind students that this is not always true. This concept can be clearly illustrated by the following example.

Example

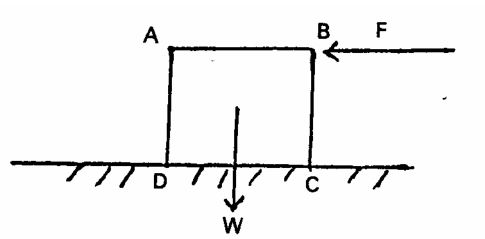
A cube of side a and weight W is placed on a rough ground. The coefficient of friction between the block and the ground is μ. A gradually increasing horizontal force F is applied at right angle to the upper edge of the block in a vertical plane through its centre of gravity as shown.

In this example, students should be led to find the magnitude of F if

(a) the block slides without toppling;

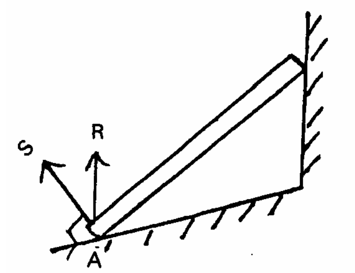
(b) the block topples over.

Moreover, the location of the normal reaction in each of the two cases described above should be investigated.



Detailed Content	Time Ratio	Notes on Teaching

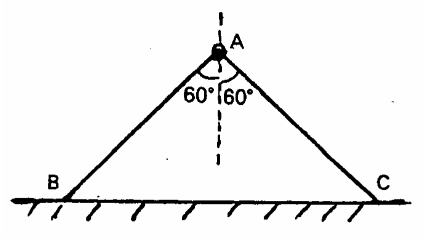
On the other hand, teachers should ensure that students can determine the correct direction of a reaction on a body. For instance, as shown in the diagram, students should know that S (instead of R) is the normal reaction on the rod at A.

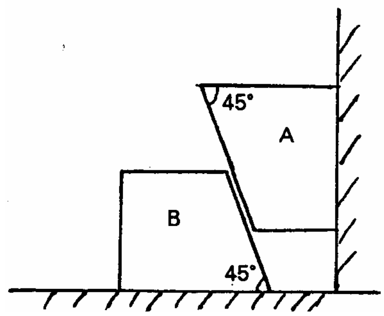


Students are expected to be familiar with the limiting positions of equilibrium of rigid bodies. Teachers should encourage students to draw free-body diagrams in solving problems.

Example 1

Two uniform rods AB, AC of equal length are freely hinged at A as shown in the diagram. AB is twice as heavy as AC. The system rests on a rough horizontal ground in a vertical plane and is in limiting equilibrium.



Detailed Content	Time Ratio	Notes on Teaching
		In this example, students should be able to determine which of the two points (B and C) will first reach the limiting equilibrium and then work out the value of the coefficient of friction between the ground and the rods. Example 2 Two blocks A and B of mass M and m (M > m) respectively are placed in contact with each other as shown in the figure. Block A rests against a rough vertical wall and block B rests on a rough horizontal ground. The coefficient of friction between block A and the wall, block A and block B, and block B and the ground are μ_1, μ_2 and μ_3 respectively.  In this example, students may be asked to find the minimum value of μ_3 required to maintain the equilibrium of the system.