EXPERIMENT 4

AIM

To determine mass of two different objects using a beam balance.

APPARATUS AND MATERIAL REQUIRED

Physical balance, weight box with a set of milligram masses and forceps, spirit level and two objects whose masses are to be determined.

DESCRIPTION OF PHYSICAL BALANCE

A physical balance is a device that measures the weight (or gravitational mass) of an object by comparing it with a standard weight (or standard gravitational mass).

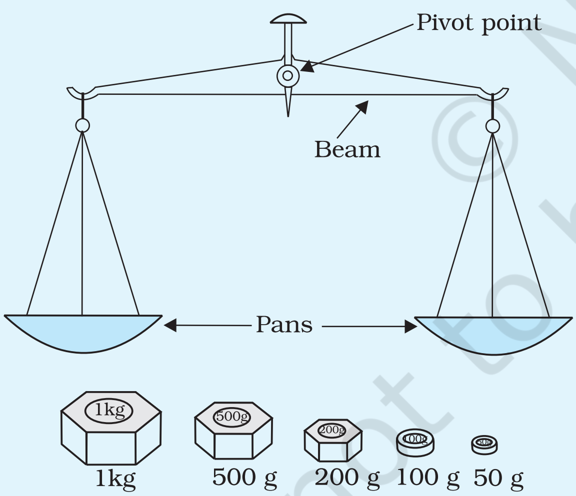

Fig. E 4.1: *A beam balance and set of weights*

The most commonly used two-pan beam balance is an application of a **lever**. It consists of a rigid uniform bar (beam), two pans suspended from each end, and a pivotal point in the centre of the bar (Fig. E 4.1). At this pivotal point, a support (called *fulcrum*) is set at right angles to the beam. This beam balance works on the principle of moments.

For high precision measurements, a physical balance (Fig. E 4.2) is often used in laboratories. Like a common beam balance, a physical balance too consists of a pair of scale pans P_1 and P_2, one at each end of a rigid beam B. The pans P_1 and P_2 are suspended through stirrups S_1 and S_2 respectively, on inverted knife-edges E_1 and E_2, respectively, provided symmetrically near the end of the beam B. The beam is also provided with a hard material (like agate) knife-edge (E) fixed at the centre pointing downwards and is supported on a vertical pillar (V) fixed on a wooden baseboard (W). The baseboard is provided with three levelling screws W_1, W_2 and W_3. In most balances, screws W_1 and W_2 are of adjustable heights and through these the baseboard W is levelled horizontally. The third screw W_3, not visible in Fig. E 4.2, is not of adjustable height and is fixed in the middle at the back of board W. When the balance is in use, the knife-edge E rests on a plane horizontal plate fixed at the top of pillar V. Thus, the central edge E acts as a *pivot* or *fulcrum* for the beam B. When the balance is not in use, the beam rests on the supports X_1 and X_2, These supports, X_1 and X_2, are fixed to another horizontal bar attached with the central pillar V. Also, the pans P_1 and P_2 rest on supports A_1 and A_2, respectively, fixed on the wooden baseboard. In some balances, supports A_1 and A_2 are not fixed and in that case the pans rest on board W, when the balance is not in use.

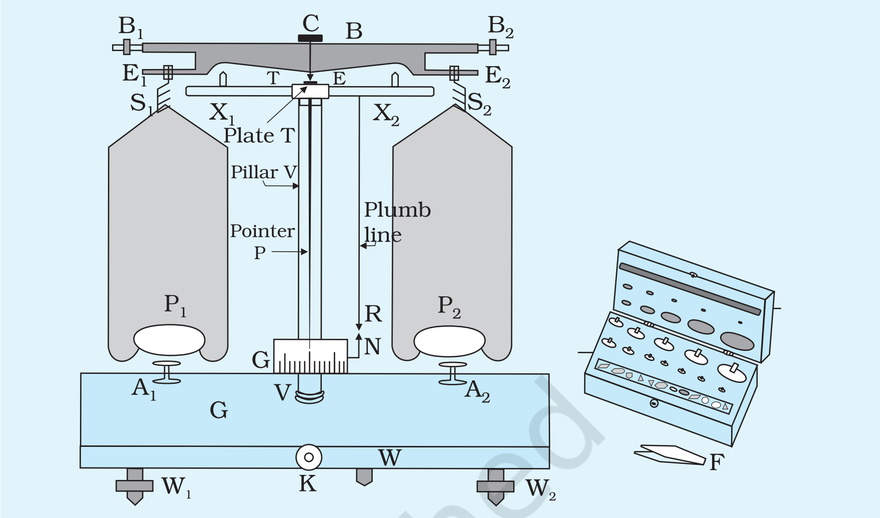

Fig. E 4.2: *A physical balance and a weight box*

At the centre of beam B, a pointer P is also fixed at right angles to it. A knob K, connected by a horizontal rod to the vertical pillar V, is also attached from outside with the board W. With the help of this knob, the vertical pillar V and supports A_1 and A_2 can be raised or lowered simultaneously. Thus, at the 'ON' position of the knob K, the beam B also gets raised and is then suspended only by the knife-edge E and oscillates freely. Along with the beam, the pans P_1 and P_2 also begin to swing up and down. This oscillatory motion of the beam can be observed by the motion of the pointer P with reference to a scale (G) provided at the base of the pillar V. When the knob K is turned back to 'OFF' position, the beam rests on supports X_1 and X_2 keeping the knife-edge E and plate T slightly separated; and the pans P_1 and P_2 rest on supports A_1 and A_2 respectively. In the 'OFF' position of the knob K, the entire balance is said to be *arrested*. Such an arresting arrangement protects the knife-edges from undue wear and tear and injury during transfer of masses (unknown and standards) from the pan.

On turning the knob K slowly to its ‘ON’ position, when there are no masses in the two pans, the oscillatory motion (or swing) of the pointer P with reference to the scale G must be same on either side of the zero mark on G. And the pointer must stop its oscillatory motion at the zero mark. It represents the vertical position of the pointer P and horizontal position of the beam B. However, if the swing is not the same on either side of the zero mark, the two balancing screws B_1 and B_2 at the two ends of the beam are adjusted. The baseboard W is levelled horizontal1y to make the pillar V vertical.

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This setting is checked with the help of plumb line (R) suspended by the side of pillar V. The appartus is placed in a glass case with two doors.

For measuring the gravitational mass of an object using a physical balance, it is compared with a standard mass. A set of standard masses (100 g, 50 g, 20 g, 10g, 5 g, 2 g, and 1 g) along with a pair of forceps is contained in a wooden box called *Weight Box*. The masses are arranged in circular grooves as shown in Fig. E 4.2. A set of milligram masses (500 mg, 200 mg, 100 mg, 50 mg, 20 mg 10 mg, 5 mg, 2 mg, and 1 mg) is also kept separately in the weight box. A physical balance is usually designed to measure masses of bodies up to 250 g.

PRINCIPLE

The working of a physical balance is based on the principle of moments. In a balance, the two arms are of equal length and the two pans are also of equal masses. When the pans are empty, the beam remains horizontal on raising the beam base by using the lower knob. When an object to be weighed is placed in the left pan, the beam turns in the anticlockwise direction. Equilibrium can be obtained by placing suitable known standard weights on the right hand pan. Since, the force arms are equal, the weight (i.e., forces) on the two pans have to be equal.

A physical balance compares forces. The forces are the weights (mass × acceleration due to gravity) of the objects placed in the two pans of the physical balance. Since the weights are directly proportional to the masses if weighed at the same place, therefore, a physical balance is used for the comparison of gravitational masses. Thus, if an object O having gravitational mass m is placed in one pan of the physical balance and a standard mass O′ of known gravitational mass m_s is put in the other pan to keep the beam the horizontal, then

Weight of body O in one pan = Weight of body O′ in other pan

Or, $$mg = m_s g$$

where g is the acceleration due to gravity, which is constant. Thus,

$$m = m_s$$

That is,

the mass of object O in one pan = standard mass in the other pan

PROCEDURE

1. Examine the physical balance and recognise all of its parts. Check that every part is at its proper place.

2. Check that set of the weight, both in gram and milligram, in the weight box are complete.

3. Ensure that the pans are clean and dry.

4. Check the functioning of arresting mechanism of the beam B by means of the knob K.

5. Level the wooden baseboard W of the physical balance horizontally with the help of the levelling screws W_1 and W_2. In levelled position, the lower tip of the plumb line R should be exactly above the fixed needle point N. Use a spirit level for this purpose.

6. Close the shutters of the glass case provided for covering the balance and slowly raise the beam B using the knob K.

7. Observe the oscillatory motion of the pointer P with reference to the small scale G fixed at the foot of the vertical pillar V. In case, the pointer does not start swinging, give a small gentle jerk to one of the pans. Fix your eye perpendicular to the scale to avoid parallax. **Caution:** Do not touch the pointer.

8. See the position of the pointer P. Check that it either stops at the central zero mark or moves equally on both sides of the central zero mark on scale G. If not, adjust the two balancing screws B_1 and B_2 placed at the two ends of the beam B so that the pointer swings equally on either side of the central zero mark or stops at the central zero mark. **Caution**: *Arrest the balance before adjusting the balancing screws.*

9. Open the shutter of the glass case of the balance. Put the object whose mass *(M)* is to be measured in the left hand pan and add a suitable standard mass say M_1, (which may be more than the rough estimate of the mass of the object) in the right hand pan of the balance in **its rest (or arrested) position**, *i.e.*, when the beam B is lowered and allowed to rest on stoppers X_1 and X_2. Always use forceps for taking out the standard mass from the weight box and for putting them back.

   The choice of putting object on left hand pan and standard masses on right hand pan is arbitrary and chosen due to the ease in handling the standard masses. A left handed person may prefer to keep the object on right hand pan and standard masses on left hand pan. It is also advised to keep the weight box near the end of board W on the side of the pan being used for putting the standard masses.

10. Using the knob K, gently raise the beam (now the beam's knife edge E will rest on plate T fixed on the top of the pillar V) and observe the motion of the pointer P. It might rest on one side of

the scale or might oscillate more in one direction with reference to the central zero mark on the scale G.

Note: Pans should not swing while taking the observations. The swinging of pans may be stopped by carefully touching the pan with the finger in the arresting position of the balance.

11. Check whether M_1 is more than M or less. For this purpose, the beam need to be raised to the full extent.

12. Arrest the physical balance. Using forceps, replace the standard masses kept in the right pan by another mass (say M_2). It should be lighter if M_1 is more than the mass M and vice versa.

13. Raise the beam and observe the motion of the pointer P and check whether the standard mass kept on right hand pan is still heavier (or lighter) than the mass M so that the pointer oscillates more in one direction. If so, repeat step 12 using standard masses in gram till the pointer swings **nearly equal** on both sides of the central zero mark on scale G. Make the standard masses kept on right hand pan to be *slightly lesser* than the mass of object. This would result in the measurement of mass M of object with a precision of 1 g. Lower the beam B.

14. For **fine measurement** of mass add extra milligram masses in the right hand pan in descending order until the pointer swings nearly equal number of divisions on either side of the central zero mark on scale G (use forceps to pick the milligram or fractional masses by their turned-up edge). In the equilibrium position *(i.e.,* when the masses kept on both the pans are equal), the pointer will rest at the centre zero mark. Close the door of the glass cover to prevent disturbances due to air draughts.

Note: The beam B of the balance should not be raised to the full extent until milligram masses are being added or removed. Pointer's position can be seen by lifting the beam very gently and for a short moment.

15. Arrest the balance and take out masses from the right hand pan one by one and note total mass in notebook. Replace them in their proper slot in the weight box. Also remove the object from the left hand pan.

16. Repeat the step 9 to step 15 two more times for the same object.

17. Repeat steps 9 to 15 and determine the mass of the second given object.

Record the observations for the second object in the table similar to Table E 4.1.

OBSERVATIONS

TABLE E 4.1: Mass of First Object

S. No.	Standard mass		Mass of the object $(x + y)$
	Gram weights, x	Milligram weights, y	
	(g)	(mg)	(g)
1			
2			
3			

Mean mass of the first object = … g

TABLE E 4.2: Mass of Second Object

S. No.	Standard mass		Mass of the object $(x + y)$
	Gram weights, x	Milligram weights, y	
	(g)	(mg)	(g)
1			
2			
3			

Mean mass of the second object = … g

RESULT

The mass of the first given object is … g and that of the second object is … g.

PRECAUTIONS

1. The correctness of mass determined by a physical balance depends on minimising the errors, which may arise due to the friction between the knife-edge E and plate T. Friction cannot be removed completely. However, it can be minimised when the knife-edge is sharp and plate is smooth. The friction between other parts of the balance may be minimised by keeping all the parts of balance dry and clean.
2. Masses should always be added in the descending order of magnitude. Masses should be placed in the centre of the pan.
3. The balance should not be loaded with masses more than capacity. Usually a physical balance is designed to measure masses upto 250 g.

4. Weighing of hot and cold bodies using a physical balance should be avoided. Similarly, active substances like chemicals, liquids and powders should *not* be kept directly on the pan.

SOURCES OF ERROR

1. There is always some error due to friction at various parts of the balance.
2. The accuracy of the physical balance is 1 mg. This limits the possible instrumental error.

DISCUSSION

The deviation of experimental value from the given value may be due to many factors.

1. The forceps used to load/unload the weights might contain dust particles sticking to it which may get transferred to the weight.
2. Often there is a general tendancy to avoid use of levelling and balancing screws to level the beam/physical balance just before using it.

SELF ASSESSMENT

1. Why is it necessary to close the shutters of the glass case for an accurate measurement?
2. There are two physical balances: one with equal arms and other with unequal arms. Which one should be preferred? What additional steps do you need to take to use a physical balance with unequal arms.
3. The minimum mass that can be used from the weight box is 10 g. Find the possible instrumental error.
4. Instead of placing the mass (say a steel block) on the pan, suppose it is hanged from the same hook S_1 on which the pan P_1 is hanging. Will the value of measured mass be same or different?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determination of density of material of a non-porous block and verification of Archimedes principle:

   Hint: First hang the small block (say steel block) from hook S_1 and determine its mass in air. Now put the hanging block in a half water-filled measuring cylinder. Measure the mass of block in water. Will it be same, more or less? Also detemine the volume of steel block. Find the density of the material of the block. From the measured masses of the steel block in air and water, verify Archimedes principle.

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