GENERAL

statics equilibrium problem physics with solution

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Understanding Static Equilibrium in Physics: A Comprehensive Guide with Step by Step Solutions

When you first encounter the term **static equilibrium**in a physics class, it often feels like a dry, abstract concept. In reality, it is a powerful tool that lets you analyze anything from a hanging picture frame to the design of bridges and skyscrapers. This article breaks down the fundamentals of static equilibrium, explains how to solve real world problems, and offers a collection of practice examples complete with detailed solutions. By the end, you'll not only know the theory but also feel confident tackling any physics equilibrium problem.

What Is Static Equilibrium?

Static equilibrium occurs when an object is at rest and all forces acting on it cancel each other out. In other words, the net force and the net torque (moment) on the body are zero. This state is governed by two key conditions:

1. Translational equilibrium – The vector sum of all external forces equals zero: :2 ôb óÒ ó à
2. Rotational equilibrium – The sum of all moments about any axis equals zero: :2 óÄ /= /0.

Because there is no net force, the object does not accelerate linearly. Because there is no net torque, the object does not rotate. These principles are rooted in Newton's first law and the definition of torque.

Why Static Equilibrium Matters

Static equilibrium is the cornerstone of many engineering disciplines. Whether you're designing a suspension bridge, a crane, or even a simple hanging lamp, you need to ensure that the structure remains stationary under all expected loads. Understanding how to calculate forces and moments in equilibrium situations is essential for safe, efficient, and cost effective design.

Key Concepts and Terminology

Before diving into problem solving, let's review the essential vocabulary you'll encounter in static equilibrium problems.

- Force (F) – A vector quantity that can push or pull an object. Measured in newtons (N).
- Weight (W) – The force of gravity on an object: W /= /mg, where m is mass and g is acceleration due to gravity.
- Normal Force (N) – The perpendicular reaction force exerted by a surface.
- Tension (T) – The force transmitted through a string, rope, or cable.
- Friction (f) – The resisting force that opposes relative motion between surfaces.
- Moment (<B' ÷" Torque – A rotational equivalent of force, calculated as <B óÒ ÷" ýr ô`, where r is the lever arm vector.
- Lever Arm (r) – The perpendicular distance from the pivot point (axis of rotation) to the line of action of the force.
- Equilibrium Conditions – As mentioned, :2 ôb óÒ ó æB £ /<B óÒ ó à

Vector Decomposition

Because forces are vectors, they have both magnitude and direction. In most problems, you'll break a force into horizontal (*Fx*) and vertical (*Fy*) components using trigonometric identities:

1. Horizontal component: Fx /= /F /cos /;€
2. Vertical component: Fy /= /F /sin /;€

Here, ;€ is the angle between the force vector and the horizontal axis.

Step by Step Approach to Solving Static Equilibrium Problems

While the mathematics can sometimes feel intimidating, a systematic approach will make any physics equilibrium problem manageable. Follow these five steps to solve most problems:

1. Draw a Free Body Diagram (FBD) – Represent all forces acting on the object with arrows. Label each force clearly.
2. Choose a Coordinate System – Typically, the x axis is horizontal and the y axis is vertical.
3. Write Equilibrium Equations – Use :2 ôg, óÒ ó Â £ /Fy /= /0, and if necessary, :2 óÄ /= /0.
4. Solve the System of Equations – Algebraic manipulation, substitution, or elimination methods.
5. Check Your Solution – Verify that all forces and moments indeed sum to zero and that units are consistent.

Let's walk through each step with illustrative examples.

1. Drawing the Free Body Diagram

Creating an accurate FBD is the backbone of any static equilibrium solution. It forces you to list every force, including contact forces, gravitational forces, and any applied loads. A common mistake is forgetting a reaction force at a support or misidentifying the direction of a tension or friction force.

For instance, consider a simple beam hanging from a ceiling by a single cable. The FBD would include:

- Weight of the beam (W) acting downward at the beam's center of mass.
- Tension in the cable (T) acting upward along the cable's line of action.
- Possibly a horizontal component if the cable is at an angle.

2. Choosing a Coordinate System

While the choice of axes is arbitrary, consistency is key. In most textbook problems, the *x axis* is horizontal and the *y axis* vertical. Align your FBD arrows accordingly so that the components are straightforward to extract.

3. Writing Equilibrium Equations

For a two dimensional problem, you'll typically have two translational equations and one rotational equation. The rotational equation is often taken about a convenient point (e.g., a support or a pivot) to eliminate unknown reaction forces from the moment sum.

Example: If a ladder leans against a wall, you might take moments about the point where the ladder touches the ground to eliminate the unknown normal force at that contact point.

4. Solving the System of Equations

Once you have all equations, you can solve them simultaneously. If you have more equations than unknowns, you're in a good position. If you have fewer, you'll need additional information (e.g., a coefficient of friction) or you'll have to make an assumption.

5. Checking Your Solution

After obtaining numerical values, plug them back into the equilibrium equations to confirm they satisfy *:2 ôg„ óÒôg', óÒ ó* and *:2 óÄ /= /0*. Also, double check units and the direction of each force to ensure consistency.

Illustrative Examples with Detailed Solutions

Example 1: A Hanging Rod

A uniform horizontal rod of length 2 m and mass 5 kg is suspended from a ceiling by a single cable attached at one end. Determine the tension in the cable.

Solution

1. Draw FBD: Weight W /= /mg /= /5 /kg /× /9.8 /m/s² /= /49 /N downward at the rod's center (1 /m from the cable).
2. Translational equilibrium: :2 ôg' óÒ ó " T /– /W /= /0 !' T /= /49 /N.
3. Rotational equilibrium: Taking moments about the cable attachment point eliminates T. The only moment is from the weight: :2 óÄ /= /0 !' W /× /1 /m /= /0 !' satisfied automatically.
4. Answer: Tension = 49 /N.

Example 2: A Beam Supported at Two Points

A 4 /m long uniform beam with a mass of 20 /kg rests on two supports: a left support at *x /= /0* and a right support at *x /= /4 /m*. The beam is horizontal. Find the reaction forces at both supports.

Solution

1. FBD: Weight W /= /20 /kg /× /9.8 /m/s² /= /196 /N acts downward at the center (2 /m from either support).
2. Translational equilibrium: :2 ôg' óÒ ó " " ò² õ" " ùb õr óÒ ó " " ò² õ" " óÒ ó "b ôâà
3. Rotational equilibrium: Take moments about left support to eliminate R •:

   :2 óÄ /= /0 !' R , /× /4 /m /– /W /× /2 /m /= /0 !' R , /= /(196 /N /× /2 /m) // /4 /m /= /98 /N.

Example 3: A Ladder Against a Wall

A 3 m ladder leans against a frictionless wall, making a 60° angle with the ground. It is held in place by a rope attached to its top and anchored to the ground 0.5 m from the wall. The ladder's mass is 10 kg. Determine the tension in the rope.

Solution

1. FBD: Weight W /= /10 /kg /× /9.8 /m/s² /= /98 /N downward at the ladder's center (1.5 /m from the wall).
2. Unknowns: Normal force at the wall (N), friction at the ground (f), tension in rope (T).
3. Choose coordinate axes: x horizontal, y vertical.
4. Translational equilibrium:

   :2 ôg, óÒ ó " â ò² õB ö6÷2 ó¸ /– /f /= /0 (;, Ò c •
5. :2 ôg' óÒ ó " b ò² õB ÷6–â ó¸ /– /W /= /0

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