Module 2 · Week 3 · Lesson

Friction and Inclined Planes

PH11-9

ORIENTATION

Lesson goal: build accurate physics fluency for friction and inclined planes and use that fluency to support clear HSC-style scientific writing.

This page is materialised into the MentorMind course shell from existing teaching, textbook, and eduKG material. Use it as the main lesson surface; use the tutor for targeted repair, worked examples, and concise writing feedback.

SYLLABUS INQUIRY QUESTION

- How do forces combine on inclined surfaces to determine motion?

From The Feynman Lectures on Physics, Vol I, Chapter 12:

Friction is not a fixed opposing force. It adjusts to the motion that would occur and only reaches a maximum value when slipping begins.

LEARNING OBJECTIVES

- Distinguish between static and kinetic friction.
- Resolve forces on an inclined plane.
- Calculate normal force and friction on slopes.
- Determine acceleration with friction present.

CONTENT

Friction Models

Friction opposes relative motion (or the tendency for relative motion) between surfaces.

Static friction (f_s) prevents sliding:

$$f_s \leq \mu_s N$$

- Adjusts from zero up to a maximum value
- Maximum occurs just before slipping begins
- μ_s is the coefficient of static friction

Kinetic friction (f_k) acts during sliding:

$$f_k = \mu_k N$$

- Constant value during sliding
- μ_k is the coefficient of kinetic friction
- Generally $\mu_k < \mu_s$

Static friction is **not always** equal to $\mu_s N$. It matches whatever force is needed to prevent motion, up to the maximum.

Interactive: Static vs Kinetic Friction

As applied force increases, friction responds:

Inclined Planes

On an inclined plane, weight must be resolved into components:

Parallel to slope (causes sliding tendency):

$$W_{\parallel} = mg \sin\theta$$

Perpendicular to slope (determines normal force):

$$W_{\perp} = mg \cos\theta$$

When no other perpendicular forces act:

$$N = W_{\perp} = mg \cos\theta$$

Interactive: Force Resolution on a Slope

A block on a 30 degrees incline with weight components:

Key insight: On a steeper slope, $W_{\parallel}$ increases and $W_{\perp}$ decreases.

Net Force on a Slope

For an object sliding down with kinetic friction:

$$F_{net} = mg\sin\theta - f_k = mg\sin\theta - \mu_k mg\cos\theta$$

$$a = g(\sin\theta - \mu_k\cos\theta)$$

Interactive: Sliding Down with Friction

A block accelerating down a slope (friction opposes motion):

Net force down slope = $20.7 - 8.9 = 11.8$ N

Acceleration = $11.8/5 = 2.4$ m/s^2

Angle of Repose

The **angle of repose** is the maximum angle before an object begins to slide:

$$\tan\theta_{max} = \mu_s$$

At this angle, $mg\sin\theta = \mu_s mg\cos\theta$, so slipping is about to begin.

WORKED EXAMPLES

Example 1: Components on a slope

A 5.0 kg block rests on a 25 degrees incline.

Solution:

1. Weight: $W = mg = 5.0 \times 9.8 = 49$ N
2. Parallel component: $W_{\parallel} = 49 \times \sin 25 degrees = 49 \times 0.423 = 20.7$ N
3. Perpendicular component: $W_{\perp} = 49 \times \cos 25 degrees = 49 \times 0.906 = 44.4$ N
4. Normal force: $N = W_{\perp} = 44.4$ N

Example 2: Sliding with kinetic friction

A 3.0 kg block slides down a 20 degrees incline with $\mu_k = 0.25$.

Solution:

1. Normal force: $N = mg\cos\theta = 3.0 \times 9.8 \times \cos 20 degrees = 27.6$ N

2. Kinetic friction: $f_k = \mu_k N = 0.25 \times 27.6 = 6.9$ N

3. Weight component down slope: $W_{\parallel} = mg \sin 20 degrees = 3.0 \times 9.8 \times \sin 20 degrees = 10.1$ N

4. Net force: $F_{net} = 10.1 - 6.9 = 3.2$ N down slope

5. Acceleration: $a = \frac{F_{net}}{m} = \frac{3.2}{3.0} = 1.1$ m/s^2

Example 3: Static friction threshold

A 4.0 kg block on a 15 degrees incline has $\mu_s = 0.40$. Will it slip?

Solution:

1. Force trying to cause slipping: $W_{\parallel} = mg \sin 15 degrees = 4.0 \times 9.8 \times \sin 15 degrees = 10.2$ N

2. Maximum static friction:

   - $N = mg \cos 15 degrees = 4.0 \times 9.8 \times \cos 15 degrees = 37.9$ N
   - $f_{s,max} = \mu_s N = 0.40 \times 37.9 = 15.2$ N

3. Since $W_{\parallel} (10.2 \text{ N}) < f_{s,max} (15.2 \text{ N})$, the block does **not** slip

4. Actual static friction: $f_s = W_{\parallel} = 10.2$ N (just enough to prevent motion)

Example 4: Pulling up an incline

A 7.0 kg crate is pulled up a 25 degrees incline at constant speed with $\mu_k = 0.20$. Find the pulling force (parallel to slope).

Solution:

1. At constant speed, $F_{net} = 0$

2. Forces parallel to slope:

   - Pull force F (up slope)
   - Weight component (down slope): $W_{\parallel} = 7.0 \times 9.8 \times \sin 25 degrees = 29.0$ N
   - Kinetic friction (down slope, opposes motion): $f_k = \mu_k N$

3. Normal force: $N = mg \cos 25 degrees = 7.0 \times 9.8 \times \cos 25 degrees = 62.2$ N

4. Kinetic friction: $f_k = 0.20 \times 62.2 = 12.4$ N

5. Equilibrium: $F = W_{\parallel} + f_k = 29.0 + 12.4 = 41.4\,\text{N}$

COMMON MISCONCEPTIONS

- **Misconception:** Friction always equals μN. **Correction:** This is only true for kinetic friction or maximum static friction. Static friction adjusts to match the applied force.
- **Misconception:** Normal force always equals weight. **Correction:** On a slope, $N = mg\cos\theta$. The steeper the slope, the smaller the normal force.
- **Misconception:** Friction always opposes applied force. **Correction:** Friction opposes relative motion (or tendency to move), not necessarily the applied force. On a slope, friction acts uphill even with no applied force.
- **Misconception:** A larger μ means more friction force. **Correction:** Friction force also depends on normal force. A low-μ surface with high N can have more friction than a high-μ surface with low N.

PRACTICE QUESTIONS

Easy (2 marks)

A 2.0 kg block is on a 30 degrees incline. Calculate the component of weight parallel to the slope.

- Use $W_{\parallel} = mg\sin\theta$ (1)
- Correct value: $W_{\parallel} = 2.0 \times 9.8 \times \sin 30 degrees = 9.8\,\text{N}$ with units (1)

Answer: 9.8 N

Medium (4 marks)

A 6.0 kg block slides down a 10 degrees incline with $\mu_k = 0.15$. Find the acceleration.

- Normal force: $N = 6.0 \times 9.8 \times \cos 10 degrees = 57.9\,\text{N}$ (1)
- Friction force: $f_k = 0.15 \times 57.9 = 8.7\,\text{N}$ (1)
- Weight component: $W_{\parallel} = 6.0 \times 9.8 \times \sin 10 degrees = 10.2\,\text{N}$ (1)
- Acceleration: $a = (10.2 - 8.7)/6.0 = 0.25\,\text{m/s^2}$ (1)

Answer: 0.25 m/s^2 down the slope

Hard (5 marks)

A 7.0 kg crate is pulled up a 25 degrees incline at constant speed with $\mu_k = 0.20$. Find the pulling force parallel to the slope.

- Recognize constant speed means $F_{net} = 0$ (1)
- Normal force: $N = 7.0 \times 9.8 \times \cos 25 degrees = 62.2$ N (1)
- Friction force (down slope): $f_k = 0.20 \times 62.2 = 12.4$ N (1)
- Weight component: $W_{\parallel} = 7.0 \times 9.8 \times \sin 25 degrees = 29.0$ N (1)
- Pull force: $F = 29.0 + 12.4 = 41.4$ N (1)

Answer: 41.4 N up the slope

MULTIPLE CHOICE QUESTIONS

Test your understanding with these interactive questions:

SUMMARY

- Static friction varies: $f_s \leq \mu_s N$; Kinetic friction is constant: $f_k = \mu_k N$
- On slopes, resolve weight: $W_{\parallel} = mg \sin\theta, W_{\perp} = mg \cos\theta$
- Normal force on a slope: $N = mg\cos\theta$
- Net force determines acceleration: $a = g(\sin\theta \pm \mu_k \cos\theta)$
- Direction of friction depends on direction of motion (or tendency to move)

SELF-ASSESSMENT

Check your understanding:

After studying this section, you should be able to:

- ☐ Explain the difference between static and kinetic friction
- ☐ Resolve weight into parallel and perpendicular components
- ☐ Calculate normal force on an inclined plane
- ☐ Determine if an object will slip using μ_s
- ☐ Find acceleration on a slope with friction

SCIENTIFIC WRITING AND EXAM SUPPORT

When answering questions from this lesson, separate:

- the physical quantity being discussed,
- the model or law being applied,
- the mathematical relationship, including units,
- the conclusion in words.

For explanation questions, write in the pattern: **claim -> physics reason -> consequence**. For calculation questions, state the formula, substitute with units, calculate, then interpret the answer.

MAINTENANCE LOOP

One-minute retrieval:

1. State the key law, model, or relationship used in this lesson.
2. Identify one common misconception that would lead to a wrong answer.
3. Write one sentence that links the calculation or evidence back to the physical meaning.

STUDENT WORKING