

# Forces, friction and motion on slopes

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer starts from the resultant-force equation and shows the substitution and the result in bold. Small differences in the last digit are acceptable when your rounding differs. Check that your free-body diagram matches the forces used in the method.

**Level:** Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB A.2

## Problem 1 Static and kinetic

1. **Static friction**, which equals the push.
2. The maximum static friction is usually larger.  **$\mu_s$  for static and  $\mu_k$  for kinetic friction.**

## Problem 2 Net force and acceleration

1.  $a = F \div m = 3000 \div 1200 = \mathbf{2.5 \text{ m/s}^2}$ .
2.  $F = ma = 1200 \times 4.0 = \mathbf{4800 \text{ N}}$ .

## Problem 3 Weight and reaction

1.  $W = 12 \times 9.81 = \mathbf{118 \text{ N}}$ .
2. The box is in equilibrium, so  $N = \mathbf{118 \text{ N}}$  upwards.

## Problem 4 Sliding crate

1.  $N = 25 \times 9.81 = \mathbf{245 \text{ N}}$ .
2.  $f = 0.30 \times 245.25 = \mathbf{73.6 \text{ N}}$ .

## Problem 5 Pulled box

1.  $60 - 22 = \mathbf{38 \text{ N}}$  to the right.
2.  $a = 38 \div 8.0 = \mathbf{4.75 \text{ m/s}^2}$ .

## Problem 6 Weight components

1.  $mg \sin \theta = 4.0 \times 9.81 \times \sin 25^\circ = 39.24 \times 0.4226 = \mathbf{16.6 \text{ N}}$ .
2.  $mg \cos \theta = 39.24 \times 0.9063 = \mathbf{35.6 \text{ N}}$ .

## Problem 7 Pushing a crate

1.  $f = 0.35 \times 40 \times 9.81 = \mathbf{137 \text{ N}}$ .
2.  $180 - 137.3 = \mathbf{43 \text{ N}}$ .

3.  $a = 42.7 \div 40 = \mathbf{1.07 \text{ m/s}^2}$ .

### Problem 8 Moving a bookcase

1.  $f_{\max} = 0.45 \times 15 \times 9.81 = \mathbf{66 \text{ N}}$ .
2.  $f = 0.32 \times 147.15 = \mathbf{47 \text{ N}}$ .
3.  $a = (66.2 - 47.1) \div 15 = \mathbf{1.3 \text{ m/s}^2}$ .

### Problem 9 Skidding car

1.  $a = \mu g = 0.80 \times 9.81 = \mathbf{7.85 \text{ m/s}^2}$ .
2.  $s = v^2 \div 2a = 625 \div 15.7 = \mathbf{39.8 \text{ m}}$ .
3.  $a = 3.92 \text{ m/s}^2$ , so  $s = 625 \div 7.848 = \mathbf{79.6 \text{ m}}$ , twice as far.

### Problem 10 Frictionless sledge

1.  $a = g \sin \theta = 9.81 \times 0.2588 = \mathbf{2.54 \text{ m/s}^2}$ .
2.  $v = \sqrt{2as} = \sqrt{2 \times 2.539 \times 20} = \mathbf{10.1 \text{ m/s}}$ .

### Problem 11 Ramp for a crate

1.  $mg \sin 20^\circ = 117.7 \times 0.3420 = \mathbf{40.3 \text{ N}}$ .
2.  $f = 0.15 \times 117.7 \times \cos 20^\circ = 0.15 \times 110.6 = \mathbf{16.6 \text{ N}}$ .
3.  $a = (40.3 - 16.6) \div 12 = \mathbf{1.97 \text{ m/s}^2}$ .

### Problem 12 Angle of slipping

1. At the limit,  $mg \sin \theta = \mu_s N = \mu_s mg \cos \theta$ , so  $\mu_s = \sin \theta \div \cos \theta = \tan \theta$ .
2.  $\mu_s = \tan 27^\circ = \mathbf{0.51}$ .

### Problem 13 Two blocks pulled

1.  $f = 0.20 \times 5.0 \times 9.81 = \mathbf{9.81 \text{ N}}$ .
2.  $a = (25 - 9.81) \div 5.0 = \mathbf{3.04 \text{ m/s}^2}$ .
3. For the 2.0 kg block:  $T - 0.20 \times 2.0 \times 9.81 = 2.0 \times 3.038$ , so  $T = 6.08 + 3.92 = \mathbf{10.0 \text{ N}}$ .

### Problem 14 Lift scale reading

1.  $N - mg = ma$ , so  $N = 70 \times (9.81 + 1.2) = \mathbf{771 \text{ N}}$ .
2.  $N = 70 \times (9.81 - 1.2) = \mathbf{603 \text{ N}}$ .
3.  $N = 70 \times 9.81 = \mathbf{687 \text{ N}}$ .

### Problem 15 Spot the slope error

1. She used  $N = mg$ , but on a slope  $\mathbf{N = mg \cos \theta}$ .

2.  $f = 0.25 \times 78.48 \times \cos 35^\circ = \mathbf{16.1\text{ N}}$ .  $mg \sin 35^\circ = 45.0\text{ N}$ , so  $a = (45.0 - 16.1) \div 8.0 = \mathbf{3.6\text{ m/s}^2}$ .

### Problem 16 Trolley and hanging mass

1.  $f = 0.10 \times 2.0 \times 9.81 = \mathbf{1.96\text{ N}}$ .

2.  $0.50 \times 9.81 - 1.962 = 2.5 \times a$ , so  $a = 2.943 \div 2.5 = \mathbf{1.18\text{ m/s}^2}$ .

3.  $T = 0.50 \times (9.81 - 1.177) = \mathbf{4.32\text{ N}}$ . Check on the trolley:  $T - 1.962 = 2.0 \times 1.177$  gives  $4.32\text{ N}$ .

### Problem 17 Pushing up a ramp

1.  $F = mg(\sin \theta + \mu \cos \theta) = 196.2 \times (0.4226 + 0.2719) = \mathbf{136\text{ N}}$ .

2.  $a = (180 - 136.3) \div 20 = \mathbf{2.19\text{ m/s}^2}$  up the ramp.

### Problem 18 Friction coefficient from data

1.  $s = \frac{1}{2}at^2$ , so  $a = 3.0 \div 1.21 = \mathbf{2.48\text{ m/s}^2}$ .

2.  $ma = mg \sin \theta - \mu mg \cos \theta$ , and the mass cancels.

3.  $\mu = (\sin 22^\circ - a \div g) \div \cos 22^\circ = (0.3746 - 0.2527) \div 0.9272 = \mathbf{0.13}$ .

### Problem 19 Car and caravan

1.  $a = (3500 - 400 - 300) \div 2000 = \mathbf{1.40\text{ m/s}^2}$ .

2. For the caravan:  $T - 300 = 800 \times 1.40$ , so  $T = \mathbf{1420\text{ N}}$ .

### Problem 20 Crate on a truck

1. Friction provides the acceleration:  $a = \mu s g = 0.40 \times 9.81 = \mathbf{3.9\text{ m/s}^2}$ .

2. The crate slides, so  $a = \mu k g = 0.30 \times 9.81 = \mathbf{2.9\text{ m/s}^2}$ .

3. Relative acceleration =  $4.5 - 2.943 = 1.557\text{ m/s}^2$ , so  $s = \frac{1}{2} \times 1.557 \times 4.0 = \mathbf{3.1\text{ m}}$ .