

# Free-body diagrams and net force problems

## AP Physics 1 (algebra-based) · Worksheet answers

Each answer shows the chosen axis, the equation, the substitution and the result in bold with its unit. Check your signs first, then the numbers, because a wrong sign changes the answer by a large amount.

**Level:** AP Physics 1 (algebra-based) · **Curriculum:** AP P1 Unit 2

### Problem 1 Forces on a book

1. Weight (gravitational force of Earth on the book) downward and the normal force of the table on the book upward.
2. The net force is **zero**, so the book stays at rest.
3. The force of the book on the table, directed downward.

### Problem 2 Net force and acceleration

1.  $a = 3000 \div 1200 = \mathbf{2.5 \text{ m/s}^2}$ .
2.  $v = at = 2.5 \times 6.0 = \mathbf{15 \text{ m/s}}$ .

### Problem 3 Weight on two worlds

1.  $W = 70 \times 9.81 = \mathbf{687 \text{ N}}$ .
2.  $W = 70 \times 1.62 = \mathbf{113 \text{ N}}$ .
3. Mass does not depend on location: **70 kg**.

### Problem 4 Forces in a line

1. Net force =  $30 - 12 - 8 = \mathbf{10 \text{ N to the right}}$ .
2.  $a = 10 \div 5.0 = \mathbf{2.0 \text{ m/s}^2}$  to the right.

### Problem 5 Bus brakes suddenly

1. The passengers have no net force on them in the forward direction once the bus slows, so they tend to keep moving forward at their original velocity (first law).
2. Friction between the road and the brakes and tyres slows the bus. The passengers continue forward until a force from the floor, a rail or a seat acts on them: **inertia, not a new forward force**.

### Problem 6 Perpendicular forces

1.  $F = \sqrt{(6.0^2 + 8.0^2)} = \mathbf{10 \text{ N}}$ .

2.  $a = 10 \div 2.0 = \mathbf{5.0 \text{ m/s}^2}$ .
3.  $\tan \theta = 8.0 \div 6.0$ , so  $\theta = \mathbf{53^\circ \text{ north of east}}$ .

### Problem 7 Hanging mass

1.  $T = mg = 4.0 \times 9.81 = \mathbf{39 \text{ N}}$ .
2.  $T - mg = ma$ ,  $T = 4.0 \times (9.81 + 2.0) = \mathbf{47 \text{ N}}$ .
3.  $T = 4.0 \times (9.81 - 2.0) = \mathbf{31 \text{ N}}$ .

### Problem 8 Reading a bathroom scale

1.  $W = 50 \times 9.81 = \mathbf{491 \text{ N}}$ .
2.  $N - mg = ma$ , so  $a = (560 - 490.5) \div 50 = \mathbf{1.4 \text{ m/s}^2}$  upward.
3. The elevator is either speeding up while moving upward or slowing down while moving downward.

### Problem 9 Third-law partners

1. The partner is the force of Diego's hand on the wall, in the opposite direction, of the same contact type.
2. The partner is the force of the exhaust gas on the rocket, directed **upward**.
3. The partner is the gravitational force of the apple on Earth, directed **upward**.

### Problem 10 Braking distance and force

1.  $v^2 = 2as$  gives  $a = 400 \div (2 \times 40) = \mathbf{5.0 \text{ m/s}^2}$  (opposite to the motion).
2.  $F = ma = 1000 \times 5.0 = \mathbf{5000 \text{ N}}$ .

### Problem 11 Dynamics from a graph

1.  $a = 6.0 \div 4.0 = 1.5 \text{ m/s}^2$ ,  $F = 2.0 \times 1.5 = \mathbf{3.0 \text{ N}}$ .
2. The velocity is constant, so the net force is **zero**.
3.  $a = -6.0 \div 2.0 = -3.0 \text{ m/s}^2$ ,  $F = 2.0 \times (-3.0) = \mathbf{-6.0 \text{ N}}$ , opposite to the direction of motion.

### Problem 12 Skydiver speeds up

1.  $W = 80 \times 9.81 = 785 \text{ N}$  downward.  $a = (785 - 500) \div 80 = \mathbf{3.6 \text{ m/s}^2}$  downward.
2. At terminal speed  $a = 0$ , so drag equals weight: **785 N**.

### Problem 13 Two blocks pushed together

1.  $a = 12 \div (2.0 + 4.0) = \mathbf{2.0 \text{ m/s}^2}$ .
2. The 4.0 kg block alone is accelerated by this contact force:  $F = 4.0 \times 2.0 = \mathbf{8.0 \text{ N}}$ .

### Problem 14 Spot the error

- Both forces act on the book. A third-law pair acts on two different objects, and the weight and normal force can differ in size (for example in an elevator).
- The partner of the weight is the **gravitational force of the book on Earth**, directed upward.

### Problem 15 Pulling a crate

- $a = 120 \cos 35^\circ \div 25 = 98.3 \div 25 = \mathbf{3.9 \text{ m/s}^2}$ .
- $N = mg - F \sin 35^\circ = 245.3 - 68.8 = \mathbf{176 \text{ N}}$ .

### Problem 16 Truck and trailer

- $a = 5600 \div (2000 + 800) = \mathbf{2.0 \text{ m/s}^2}$ .
- The coupling accelerates only the trailer:  $T = 800 \times 2.0 = \mathbf{1600 \text{ N}}$ .
- The tension must accelerate only the trailer, while the 5600 N also accelerates the truck itself.

### Problem 17 Loaded lift cable

The total mass is 1500 kg.

- $T = 1500 \times (9.81 + 0.80) = \mathbf{1.6 \times 10^4 \text{ N}}$  (15 900 N).
- $a = -1.5 \text{ m/s}^2$ :  $T = 1500 \times (9.81 - 1.5) = \mathbf{1.2 \times 10^4 \text{ N}}$  (12 500 N).
- $T = 1500 \times 9.81 = \mathbf{1.5 \times 10^4 \text{ N}}$  (14 700 N).

### Problem 18 Bob in an accelerating van

- Two forces act on the bob: weight  $mg$  downward and tension  $T$  along the string, up and towards the front. The vertical component of  $T$  balances weight and the horizontal component produces the acceleration.
- $T \cos \theta = mg$  and  $T \sin \theta = ma$ , so  $\tan \theta = a \div g = 2.5 \div 9.81 = 0.255$  and  $\theta = \mathbf{14^\circ}$ .
- $T = mv\sqrt{g^2 + a^2} = 0.20 \times \sqrt{(96.2 + 6.25)} = 0.20 \times 10.12 = \mathbf{2.0 \text{ N}}$ .

### Problem 19 Finding the mass from data

- Gradient =  $(2.01 - 0.51) \div (4.0 - 1.0) = \mathbf{0.50 \text{ m/s}^2 \text{ per N}}$ .
- Gradient =  $1 \div m$ , so  $m = 1 \div 0.50 = \mathbf{2.0 \text{ kg}}$ .
- A negative a-intercept means that part of the applied force is needed to overcome a resistive force such as friction before the trolley accelerates.

### Problem 20 Truck against mosquito

By Newton's third law the force of the truck on the mosquito and the force of the mosquito on the truck are equal in magnitude, opposite in direction and act on different objects. The

accelerations differ because  $a = F \div m$ : the tiny mass of the mosquito gives a huge acceleration, while the truck's change in velocity is negligible. The ratio is  $a_{\text{mosquito}} \div a_{\text{truck}} = m_{\text{truck}} \div m_{\text{mosquito}} = 5000 \div (2.0 \times 10^{-6}) = \mathbf{2.5 \times 10^9}$ .