Newton's Laws, Free-Body Diagrams, Inclines, and Friction Worksheet

Burke Tutoring In Fremont · 27 problems in five parts · answer key at the end

Name _____ Class _____ Date _____

Directions. Draw a free-body diagram for every problem before you write any equations, and label each force with its type and the object exerting it. Use g = 9.8 m/s². Round final answers to three significant figures and keep unrounded values between steps.

Guide, incline animation, and worked examples: burketutoringinfremont.com/ap-physics-1-dynamics-study-guide/

Part A: Newton's three laws

Net force, mass and weight, and third-law pairs.

1. An astronaut has a mass of 72.0 kg. Find her weight on Earth and on the Moon, where g = 1.62 m/s². What is her mass on the Moon?

2. A 0.165 kg hockey puck slides across level, frictionless ice at a constant 8.0 m/s. What is the net force on the puck, and which forces act on it?

3. Two horizontal forces act on a 5.00 kg crate on a frictionless floor: 30.0 N east and 12.0 N west. Find the acceleration of the crate.

4. A 1,250 kg car speeds up with constant acceleration from rest to 18.0 m/s in 6.00 s on a straight, level road. Find the net force on the car.

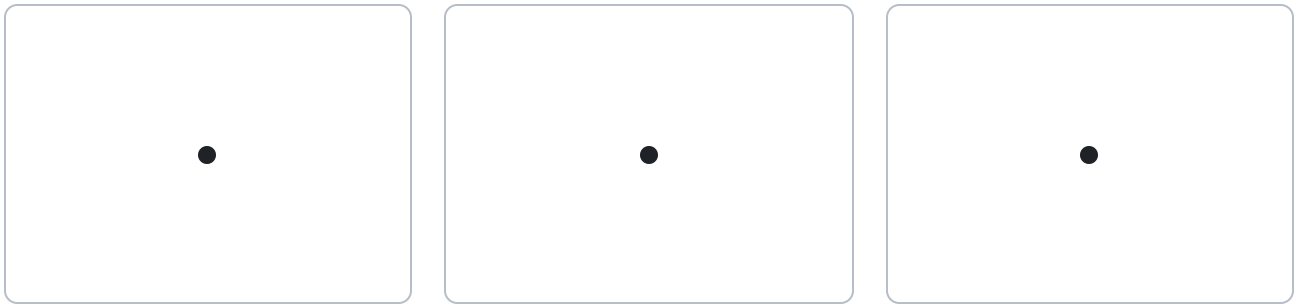
5. A 60.0 kg skater and a 40.0 kg skater stand at rest on frictionless ice and push off each other. During the push, the 60.0 kg skater accelerates at 1.20 m/s^2. Find the force each skater exerts on the other and the acceleration of the 40.0 kg skater.

6. A lamp hangs at rest from a cable attached to the ceiling. (a) The cable pulls up on the lamp. What is the third-law partner of that force? (b) What is the third-law partner of Earth's gravitational force on the lamp? (c) The tension and the weight of the lamp are equal in size. Are they a third-law pair?

Part B: Free-body diagrams and the second law

Normal force, tension, and forces at an angle on level ground and in elevators.

7. Draw a free-body diagram for each object, and label every force with its type and the object exerting it. (a) A ball moving upward after it leaves your hand, with air resistance neglected. (b) A sled sliding to the right and slowing down on level snow. (c) A bucket raised at constant speed by a rope.



(a) (b) (c)

8. A 55.0 kg student stands on a scale in an elevator. What does the scale read when the elevator (a) moves upward at constant speed, (b) speeds up while moving upward at 1.60 m/s², (c) speeds up while moving downward at 1.60 m/s²?

9. A 10.0 kg box sits on a frictionless floor. A rope pulls on it with a tension of 40.0 N at 30.0° above the horizontal. Find the acceleration of the box and the normal force on it.

10. A student pushes a 20.0 kg crate across a frictionless floor with a force of 80.0 N directed 25.0° below the horizontal. Find the normal force on the crate and its acceleration.

11. A rope lifts a 5.00 kg bucket of water straight up with an upward acceleration of 2.00 m/s^2. Find the tension in the rope. What would the tension be if the bucket rose at constant speed?

12. A 0.200 kg air freshener hangs from a string attached to the rearview mirror of a car. While the car speeds up on a level road at 2.50 m/s^2, the string hangs at a steady angle from the vertical. Find the angle and the tension in the string.

Part C: Inclines without friction

Components of gravity, normal force, and motion along the slope.

13. A 3.00 kg block slides down a frictionless incline at 35.0°. Find the components of the gravitational force along and perpendicular to the incline, the normal force, and the acceleration of the block.

14. A cart is released from rest at the top of a frictionless ramp 2.40 m long, inclined at 12.0°. Neglect the rotational inertia of the cart's wheels. How long does it take to reach the bottom, and how fast is it moving there?

15. A 1.50 kg cart on a frictionless track inclined at 20.0° is held at rest by a string parallel to the track. Find the tension in the string and the normal force from the track.

16. A block slides up a frictionless incline at 30.0° with an initial speed of 6.00 m/s. How far up the incline does it go before stopping, and how long after it starts does it return to its starting point?

17. A cart rolls down a long track with negligible friction, and its measured acceleration is 1.70 m/s^2. Neglect the rotational inertia of the cart's wheels. At what angle is the track inclined?

18. A block moving at 2.00 m/s at the top of a frictionless incline at 15.0° continues down the slope. How long does it take to travel 5.00 m along the incline?

Part D: Static and kinetic friction

Level floors, braking, slip angles, and blocks on rough inclines.

19. A 25.0 kg crate rests on a level floor with $\mu_s = 0.400$ and $\mu_k = 0.300$. (a) What friction force acts if you push horizontally with 60.0 N? (b) What horizontal push starts the crate moving? (c) Once it slides, what push keeps it moving at constant velocity?

20. A hockey puck slides across a level rink from an initial speed of 12.0 m/s and stops in 48.0 m. Find the coefficient of kinetic friction between the puck and the ice.

21. A 1,400 kg car traveling at 25.0 m/s locks its brakes and skids to a stop on a level road. The coefficient of kinetic friction between the tires and the road is 0.700. Find the stopping distance. Would a heavier car with the same tires skid farther?

22. A coin rests on a book. One end of the book is raised slowly, and the coin starts to slide when the cover makes a 28.0° angle with the horizontal. Find the coefficient of static friction between the coin and the cover.

23. A 4.00 kg block slides down an incline at 30.0° with $\mu_k = 0.200$. Find the friction force on the block and its acceleration.

24. A 6.00 kg box rests on a ramp at 25.0° with $\mu_s = 0.600$. (a) Does it slide? (b) Find the static friction force on the box and the largest static friction force the ramp could supply at this angle.

Challenge problems

Several ideas in one problem.

25. A worker pushes a 30.0 kg crate up a ramp inclined at 20.0° with a force parallel to the ramp. The crate moves at constant velocity, and $\mu_k = 0.250$. Find the size of the push.

26. A block is launched up an incline at 30.0° with an initial speed of 5.00 m/s. The coefficients of friction are $\mu_s = 0.300$ and $\mu_k = 0.200$. (a) How far up the incline does it slide? (b) Does it stay there or slide back down? (c) If it slides back, find its speed when it returns to the starting point.

27. A 1.20 kg book is pressed against a vertical wall by a horizontal push. The coefficient of static friction between the book and the wall is 0.500. Find the smallest push that keeps the book from sliding down.

Answer key

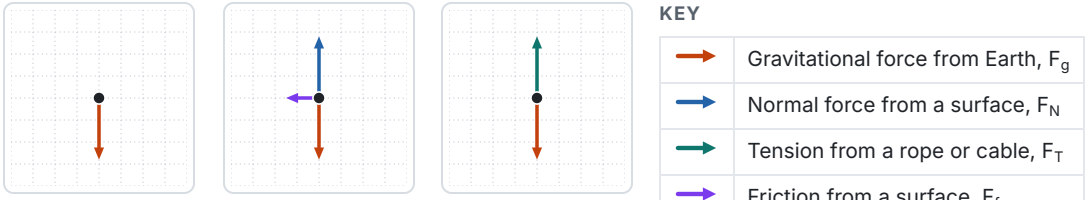
Worked answers for all 27 problems, with g = 9.8 m/s².

Part A: Newton's three laws

1. Earth: 72.0 × 9.8 = 706 N. Moon: 72.0 × 1.62 = 117 N. Her mass is 72.0 kg in both places, because mass does not depend on location.
2. The net force is 0 N. The velocity is constant, so the acceleration is zero and ΣF = 0 (first law). Two forces act: gravity, 0.165 × 9.8 = 1.62 N down, and the normal force from the ice, 1.62 N up. No horizontal force is needed to keep the puck moving.
3. ΣF = 30.0 − 12.0 = 18.0 N east, so a = 18.0 / 5.00 = 3.60 m/s² east.
4. a = 18.0 / 6.00 = 3.00 m/s², so ΣF = ma = 1,250 × 3.00 = 3,750 N in the direction of motion.
5. The force on the 60.0 kg skater is 60.0 × 1.20 = 72.0 N. By the third law, the 40.0 kg skater feels 72.0 N in the opposite direction, so the 40.0 kg skater accelerates at 72.0 / 40.0 = 1.80 m/s², in the opposite direction.
6. (a) The lamp pulls down on the cable with a force of the same size. (b) The lamp's gravitational pull on Earth, upward and the same size as the lamp's weight. (c) No. Both forces act on the lamp, and they are different types of force. They are equal in size because the lamp's acceleration is zero.

Part B: Free-body diagrams and the second law

7. (a) One force: gravity from Earth, straight down. The hand no longer touches the ball, so nothing pushes it upward. (b) Gravity down, the normal force from the snow up (equal in size to gravity), and kinetic friction from the snow pointing left, opposite the sliding. (c) Tension from the rope up and gravity down, equal in size because the velocity is constant.



(a) Ball after it leaves the hand

(b) Sled sliding to the right, slowing down

(c) Bucket rising at constant speed

8. The scale reads the normal force, $F_N = m(g + a)$ with up positive. (a) a = 0: 55.0 × 9.8 = 539 N. (b) a = +1.60 m/s²: 55.0 × 11.4 = 627 N. (c) Speeding up while moving down means the acceleration points down, a = −1.60 m/s²: 55.0 × 8.2 = 451 N.
9. Horizontal: a = 40.0 cos 30.0° / 10.0 = 3.46 m/s². Vertical: $F_N = mg - F_T \sin 30.0° = 98.0 - 20.0 = 78.0$ N.
10. Vertical: $F_N = mg + F \sin 25.0° = 196 + 33.8 = 230$ N. Horizontal: a = 80.0 cos 25.0° / 20.0 = 3.63 m/s². Pushing down at an angle makes F_N larger than mg.
11. $F_T - mg = ma$, so $F_T = 5.00(9.8 + 2.00) = 59.0$ N. At constant speed, a = 0 and $F_T = mg = 49.0$ N.
12. Horizontal: $F_T \sin \varphi = ma$. Vertical: $F_T \cos \varphi = mg$. Dividing gives $\tan \varphi = a / g = 2.50 / 9.8$, so φ = 14.3°, with the air freshener swung toward the back of the car. $F_T = m\sqrt{(g^2 + a^2)} = 0.200 \times \sqrt{(9.8^2 + 2.50^2)} = 2.02$ N.

Part C: Inclines without friction

13. $F_g = 3.00 \times 9.8 = 29.4$ N. Along the incline: 29.4 sin 35.0° = 16.9 N, down the slope. Perpendicular: 29.4 cos 35.0° = 24.1 N, into the surface. $F_N = 24.1$ N. a = 9.8 sin 35.0° = 5.62 m/s² down the slope.

14. $a = 9.8 \sin 12.0° = 2.04\ m/s^2$. $t = \sqrt{(2\Delta x / a)} = \sqrt{(2 \times 2.40 / 2.0375)} = 1.53$ s. $v = at = 3.13$ m/s.

15. Along the slope: $F_T = mg \sin 20.0° = 14.7 \times 0.342 = 5.03$ N, up the slope. Perpendicular: $F_N = mg \cos 20.0° = 13.8$ N.

16. $a = 9.8 \sin 30.0° = 4.90\ m/s^2$ down the slope, the same on the way up and on the way down. Distance: $v_0^2 / (2a) = 36.0 / 9.80 = 3.67$ m. Time up: $6.00 / 4.90 = 1.22$ s. The trip down takes the same time, so it returns after 2.45 s, moving at 6.00 m/s down the slope.

17. $a = g \sin \theta$, so $\sin \theta = 1.70 / 9.8 = 0.1735$ and $\theta = 9.99°$.

18. $a = 9.8 \sin 15.0° = 2.536\ m/s^2$. $\Delta x = v_0 t + \frac{1}{2}at^2$ gives $5.00 = 2.00t + 1.268t^2$, or $1.268t^2 + 2.00t - 5.00 = 0$. The quadratic formula gives $t = [-2.00 + \sqrt{(4.00 + 4(1.268)(5.00))}] / (2 \times 1.268) = 1.35$ s. The other root is negative, so it is rejected.

Part D: Static and kinetic friction

19. $F_N = mg = 245$ N. (a) The largest static friction is $0.400 \times 245 = 98.0$ N. A 60.0 N push is less than that, so the crate stays at rest and static friction is 60.0 N, opposite the push. (b) Any push greater than 98.0 N. (c) Constant velocity needs $\Sigma F = 0$, so the push equals kinetic friction: $0.300 \times 245 = 73.5$ N.

20. $a = v_0^2 / (2\Delta x) = 144 / 96.0 = 1.50\ m/s^2$. On level ice $F_N = mg$, so $a = \mu_k g$ and $\mu_k = 1.50 / 9.8 = 0.153$.

21. $a = \mu_k g = 0.700 \times 9.8 = 6.86\ m/s^2$. $\Delta x = v^2 / (2a) = 625 / 13.72 = 45.6$ m. No. A heavier car has a larger friction force but also more mass to stop, and the mass cancels, so with the same speed and μ_k it skids the same distance.

22. At the slip angle, $mg \sin \theta = \mu_s mg \cos \theta$, so $\mu_s = \tan 28.0° = 0.532$.

23. $F_N = mg \cos 30.0° = 33.9$ N, so $F_f = 0.200 \times 33.9 = 6.79$ N, up the slope. $a = g(\sin 30.0° - 0.200 \cos 30.0°) = 3.20\ m/s^2$ down the slope.

24. (a) No: $\tan 25.0° = 0.466$, which is less than 0.600. (b) Static friction balances the along-slope component of gravity: $F_f = 6.00 \times 9.8 \times \sin 25.0° = 24.8$ N, up the slope. The largest possible value is $0.600 \times 6.00 \times 9.8 \times \cos 25.0° = 32.0$ N. The actual friction is less than the maximum.

Challenge problems

25. Moving up the slope, kinetic friction points down the slope. Constant velocity means $\Sigma F = 0$ along the slope: $F = mg \sin 20.0° + \mu_k mg \cos 20.0° = 100.6 + 69.1 = 170$ N.

26. (a) On the way up, friction and the along-slope part of gravity both point down the slope: $a = g(\sin 30.0° + 0.200 \cos 30.0°) = 6.60\ m/s^2$. Distance: $5.00^2 / (2 \times 6.597) = 1.89$ m. (b) $\tan 30.0° = 0.577$ is greater than 0.300, so static friction cannot hold the block, and it slides back. (c) On the way down, friction points up the slope: $a = g(\sin 30.0° - 0.200 \cos 30.0°) = 3.20\ m/s^2$. $v = \sqrt{(2 \times 3.203 \times 1.895)} = 3.48$ m/s. It returns slower than it left because kinetic friction opposed the sliding in both directions.

27. The push and the normal force are the only horizontal forces, so F_N equals the push. Static friction from the wall points up and must balance gravity: $mg \le \mu_s F_N$. The push must be at least $mg / \mu_s = 11.76 / 0.500 = 23.5$ N.