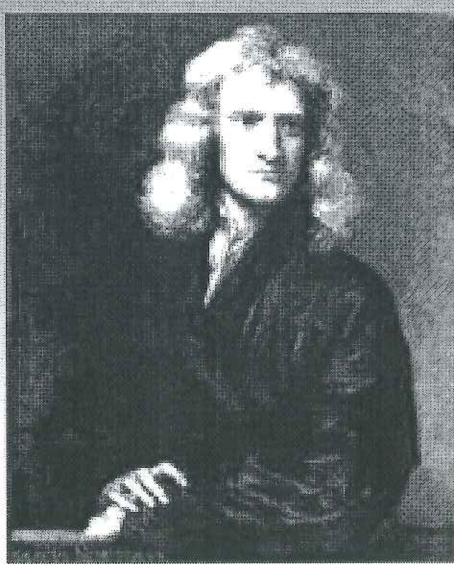
Lecture 9

(Ch4:2-3)

Chapter 4:Force and Newton's Laws

- *Force and Mass*
- *Newton's Laws of Motion*
- *Applications of Newton's Laws*
- *Uniform Circular Motion*
- *Friction and Drag*

Newton's First Law of Motion

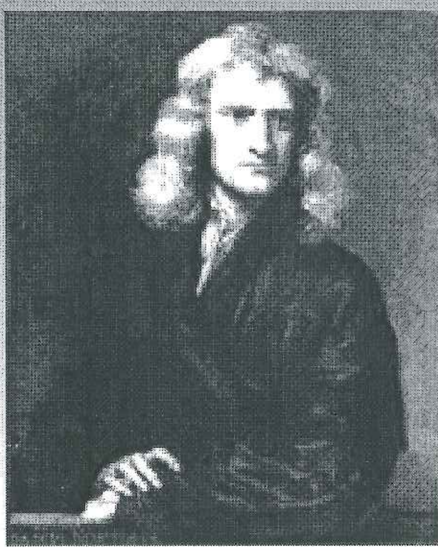


Isaac Newton
(1642–1727)

"Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon."

Isaac Newton,
Mathematical Principles of Natural Philosophy, 1687

Newton's Second Law of Motion

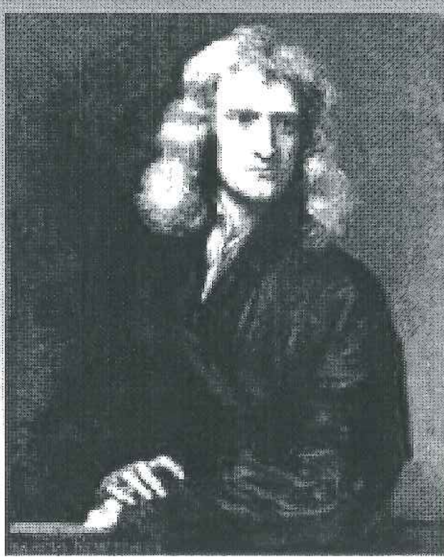


Isaac Newton
(1642–1727)

"The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed."

Isaac Newton,
Mathematical Principles of Natural Philosophy, 1687

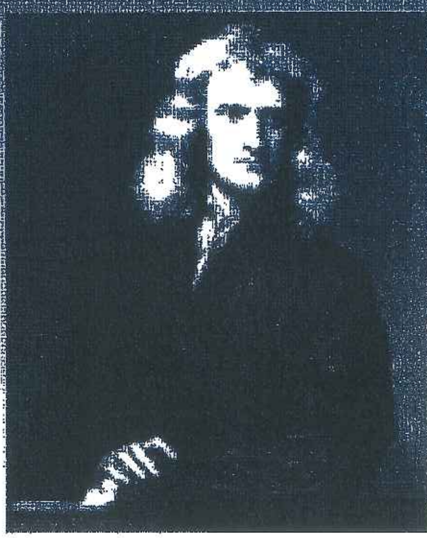
Newton's Laws of Motion



Isaac Newton
(1642–1727)

- *Dynamics* is the study of the motion of objects under the action of forces.
- A *force* is a push or a pull.
- Newton's laws are applicable in *inertial reference frames.*

Newton's Third Law of Motion



Isaac Newton
(1642–1727)

"To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."

Isaac Newton,
Mathematical Principles of Natural Philosophy, 1687

Newton's Second Law of Motion

$$\vec{F}_{net} = m\vec{a}$$

- The direction of the acceleration is the same as the direction of the applied force.
- $m\vec{a}$ is *not* a force.
- Force has dimensions ML/T^2.
- The SI unit of force, the newton, is equivalent to kg-m/s^2.

$F \Rightarrow [N]$

$1N = 1kg \cdot 1\frac{m}{s^2}$

Chapter 4:Force and Newton's Laws
Newton's Second Law in Component Form

$$\vec{F}_{net} = m \cdot \vec{a}\text{, in SI: } \frac{1\,\text{kg} \cdot 1\,\text{m}}{1\,s^2} = 1\,\text{N}$$

In the x-y plane we can work on the x-component and y-component of the force and acceleration.

$$F_{net,x} = m \cdot a_x \quad \text{the } (x-\text{component})$$

$$F_{net,y} = m \cdot a_y \quad \text{the } (y-\text{component})$$

In terms of magnitude and direction, we have

$$F_{net} = \sqrt{F_{net,x}^2 + F_{net,y}^2} \quad \text{the magnitude of } \vec{F}_{net}$$

$$\theta = \tan^{-1}\left(\frac{F_{net,y}}{F_{net,x}}\right)$$

Adding Vectors by Components

$$\vec{A} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$$

$$\vec{B} = b_x\hat{i} + b_y\hat{j} + b_z\hat{k}$$

$$\vec{A} + \vec{B} = (a_x + b_x)\hat{i} + (a_y + b_y)\hat{j} + (a_z + b_z)\hat{k}$$

$$\vec{A} - \vec{B} = (a_x - B_x)\hat{i} + (a_y - b_y)\hat{j} + (a_z - b_z)\hat{k}$$

$$m\vec{A} = ma_x \cdot \hat{i} + mb_y \cdot \hat{j} + ma_z \cdot \hat{k}$$

Chapter 4:Force and Newton's Laws

Newton's Second Law in Component Form

Just like the force, the acceleration can also be used in the component form.

$$a_x = \frac{F_{net,x}}{m} \quad \text{the } (x-\text{component})$$

$$a_y = \frac{F_{net,y}}{m} \quad \text{the } (y-\text{component})$$

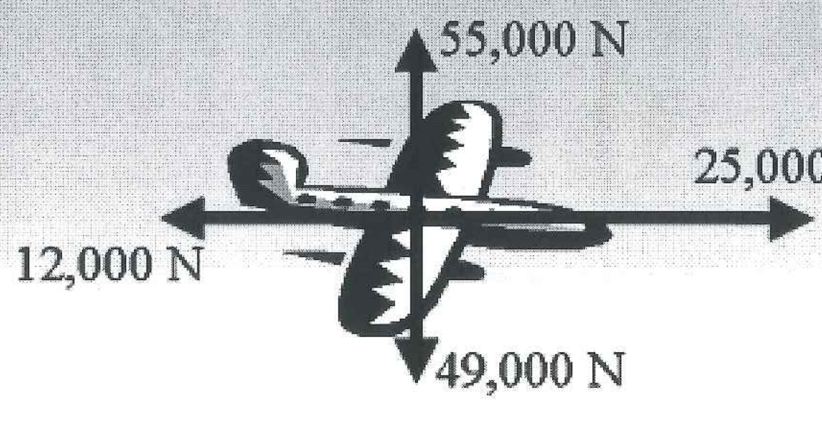
In terms of magnitude and direction, we have

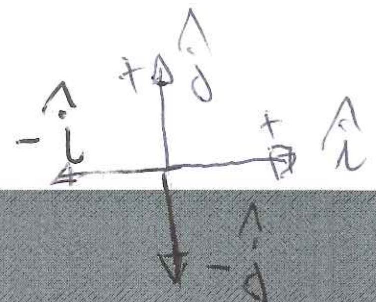
$$a = \sqrt{a_x^2 + a_y^2} = \frac{F_{net}}{m} \quad \text{the magnitude of } \vec{a}$$

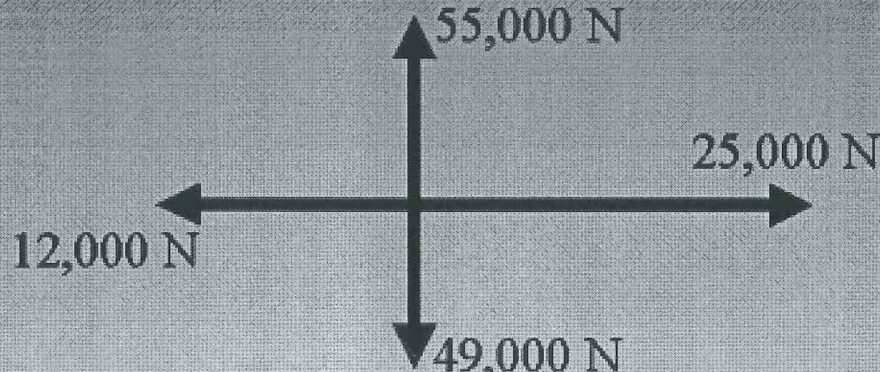
$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right) = \tan^{-1}\left(\frac{F_{net,y}}{F_{net,x}}\right)$$

Newton's Second Law of Motion

Forces acting an 5,000 kg airplane are depicted below. What is the acceleration of the airplane?







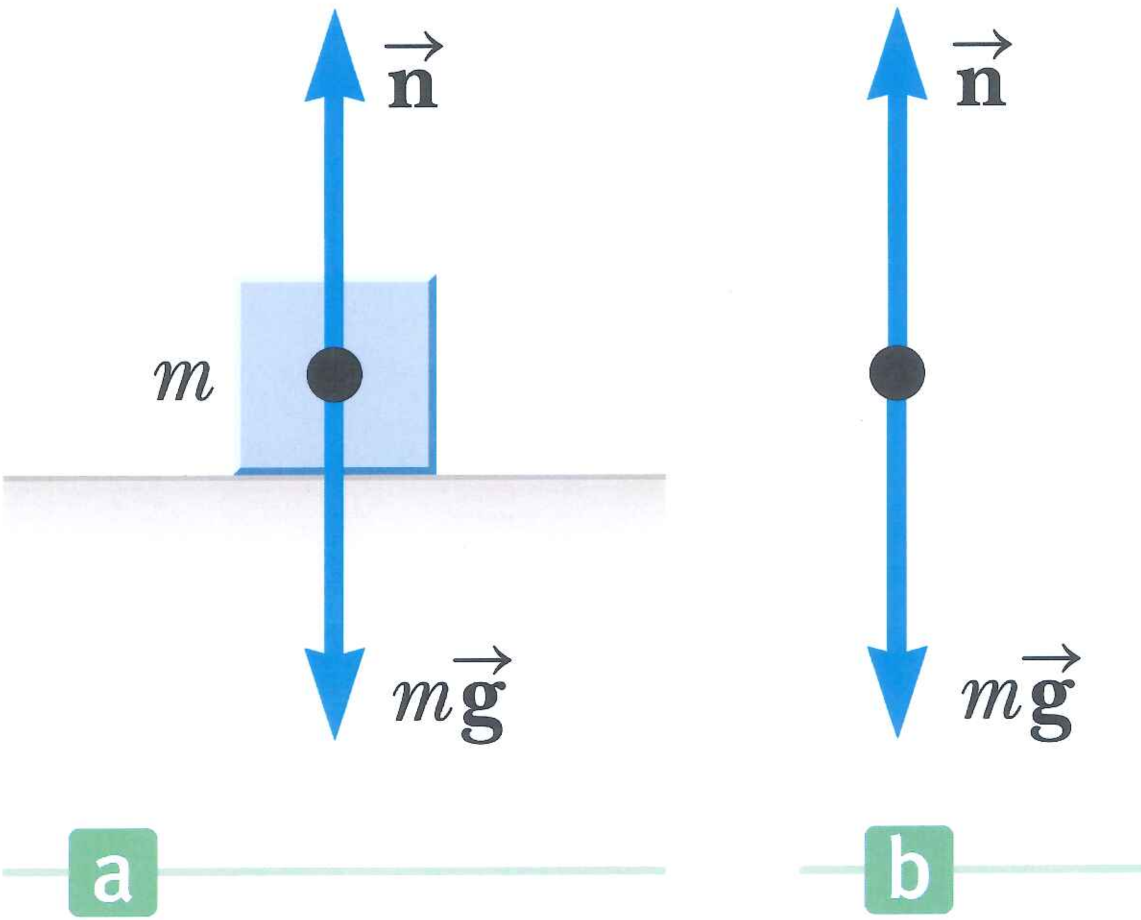
$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4$$

$$\vec{F}_{net} = -12000\hat{i} + 55000\hat{j} - 49000\hat{j} + 25000\hat{i}$$

$$\vec{F}_{net} = 13000\,N\,\hat{i} + 6000\,N\,\hat{j}$$

$$\vec{a} = \frac{\vec{F}}{m} = \frac{13000}{5000}\hat{i} + \frac{6000}{5000}\hat{j} = 2.6\,\tfrac{m}{s^2}\,\hat{i} + 1.2\,\tfrac{m}{s^2}\,\hat{j}$$

Case 1: The Normal Force on a Level Surface

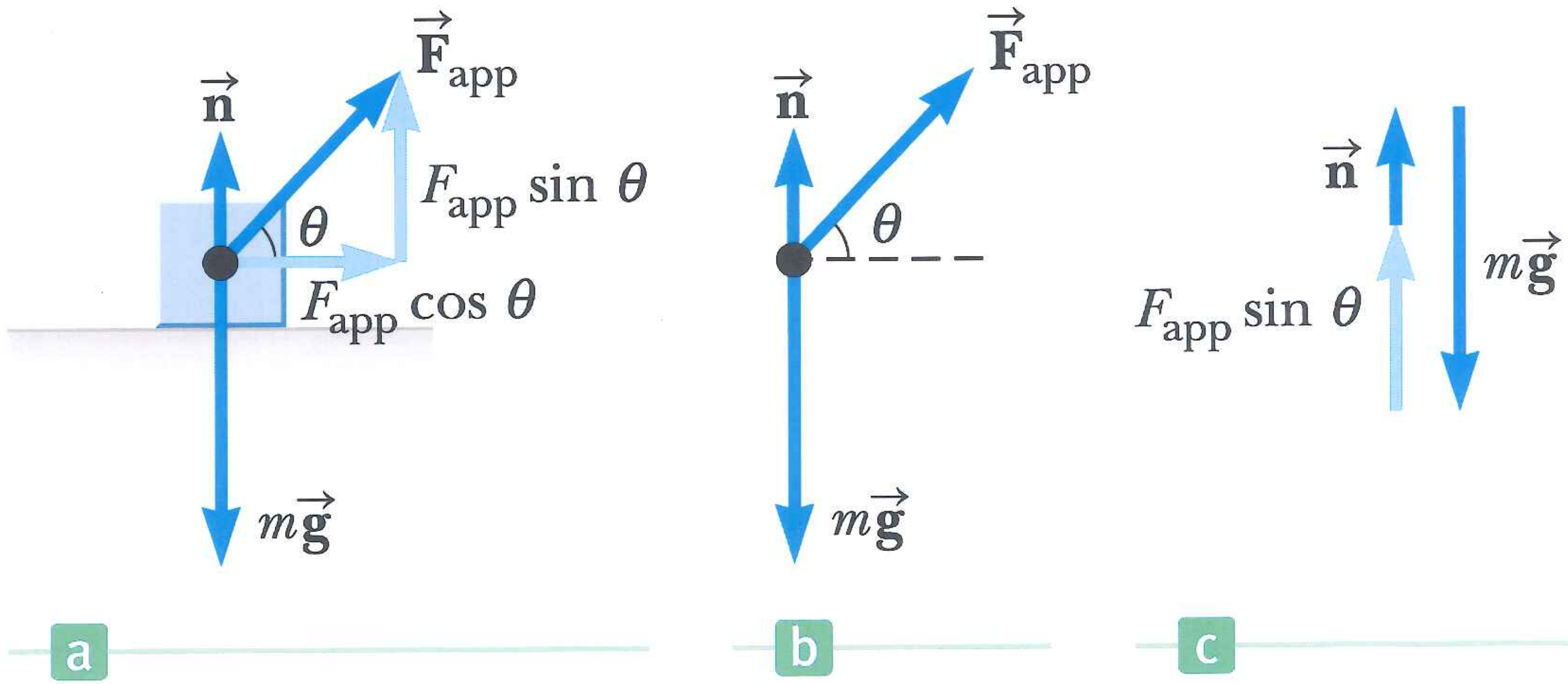


$$\Sigma F_y = ma_y$$

$$n - mg = 0$$

$$n = mg$$

Case 2: The Normal Force on a Level Surface with an Applied Force



$$\Sigma F_y = ma_y$$

$$n - mg + F_{app} \sin\theta = 0$$

$$n = mg - F_{app} \sin\theta$$

25. A rocket takes off from Earth's surface, accelerating straight up at 72.0 m/s^2. Calculate the normal force acting on an astronaut of mass 85.0 kg, including his space suit.

4.25 Two forces act on the astronaut, resulting in an upward acceleration a_y = +72.0 m/s². As in Section 4.3, Case 4, apply the y-component of Newton's second law to find

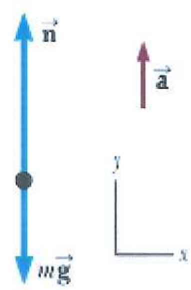
$$\Sigma F_y = ma_y$$

$$n - mg = ma_y$$

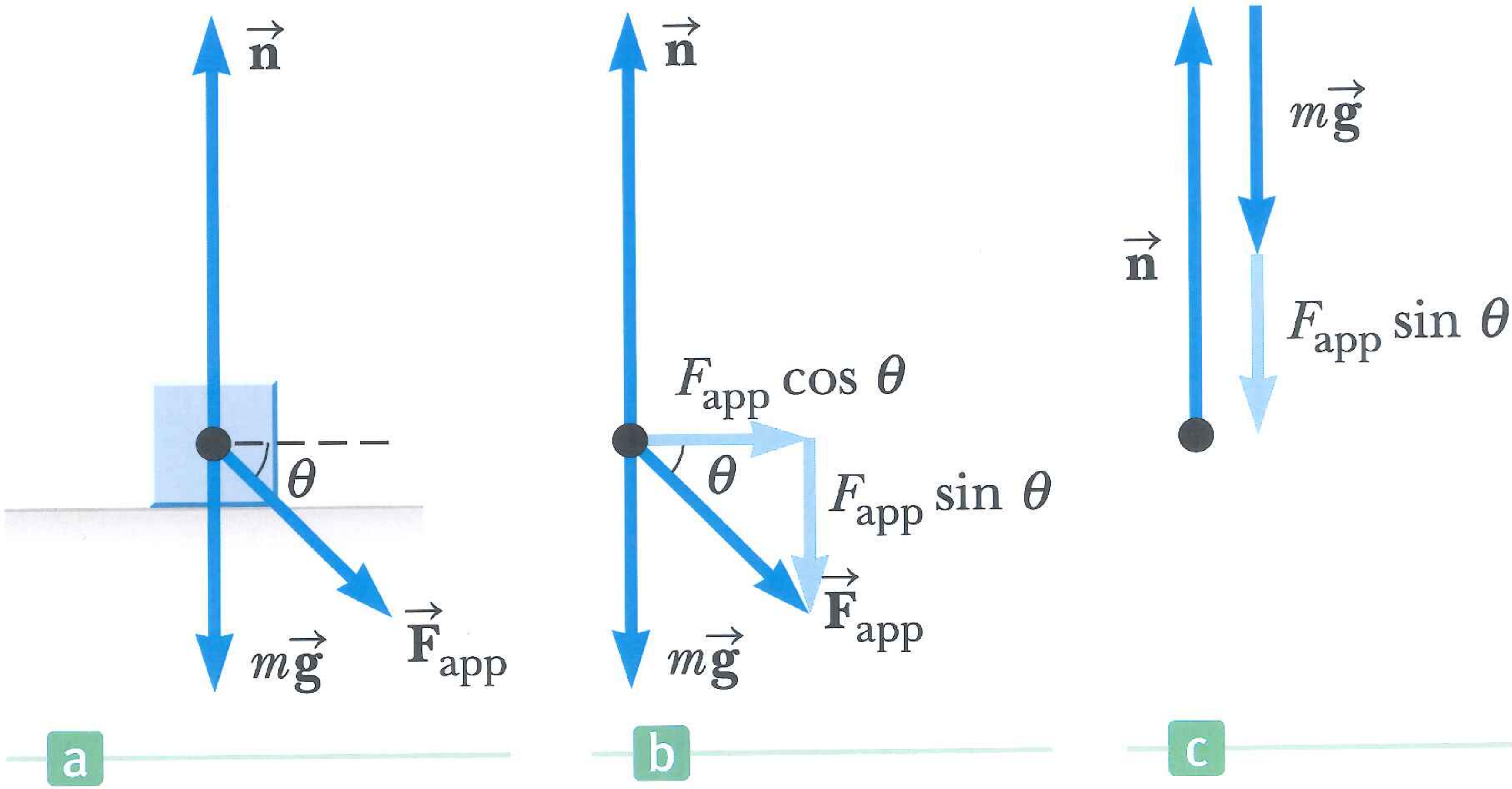
$$n = mg + ma_y = m(g + a_y)$$

$$= (85.0 \text{ kg})(9.80 \text{ m/s}^2 + 72.0 \text{ m/s}^2)$$

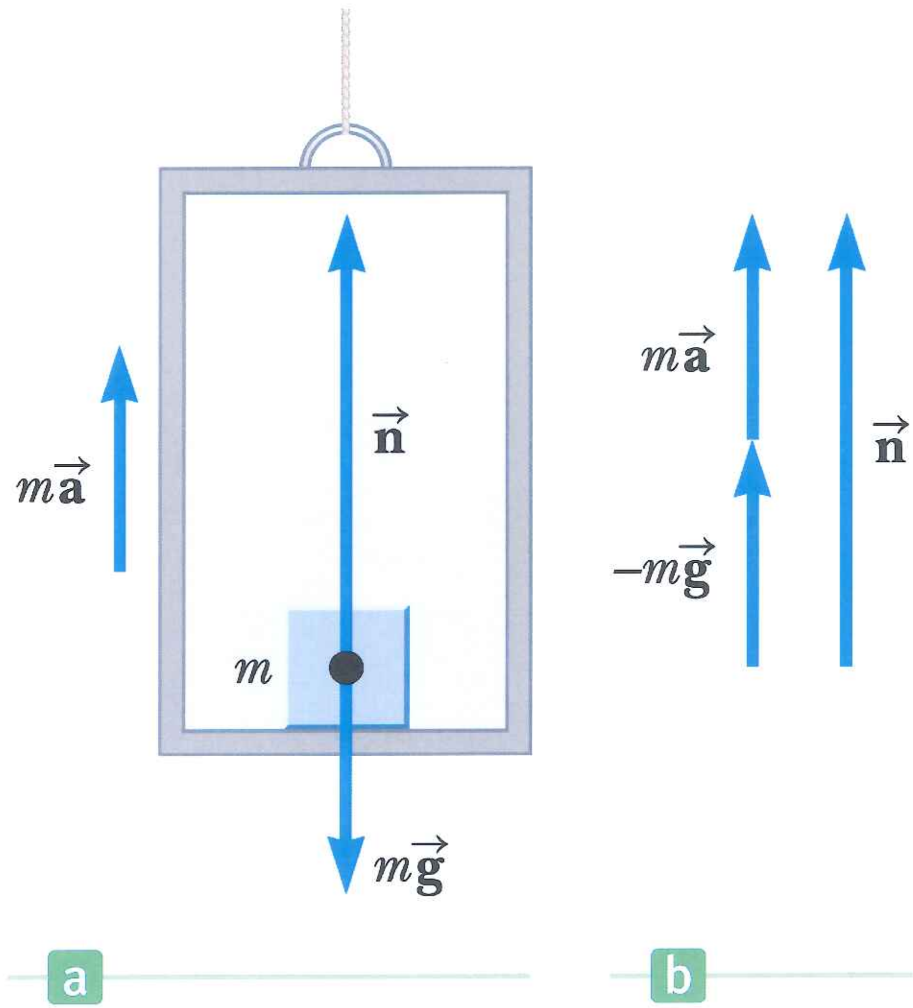
$$= \boxed{6.95 \times 10^3 \text{ N}}$$



Case 2: The Normal Force on a Level Surface with an Applied Force



Case 3: The Normal Force on a Level Surface Under Acceleration

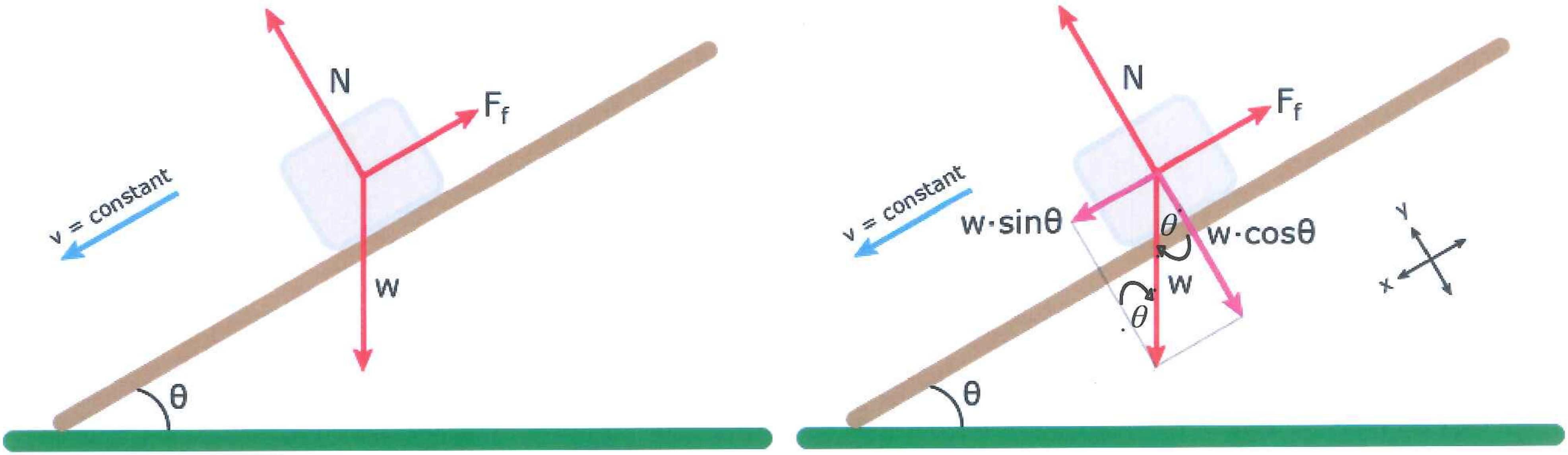


$$\Sigma F = ma \rightarrow$$

$$n - mg = ma$$

$$n = ma + mg$$

Chapter 4:Force and Newton's Laws
Motion on an Incline



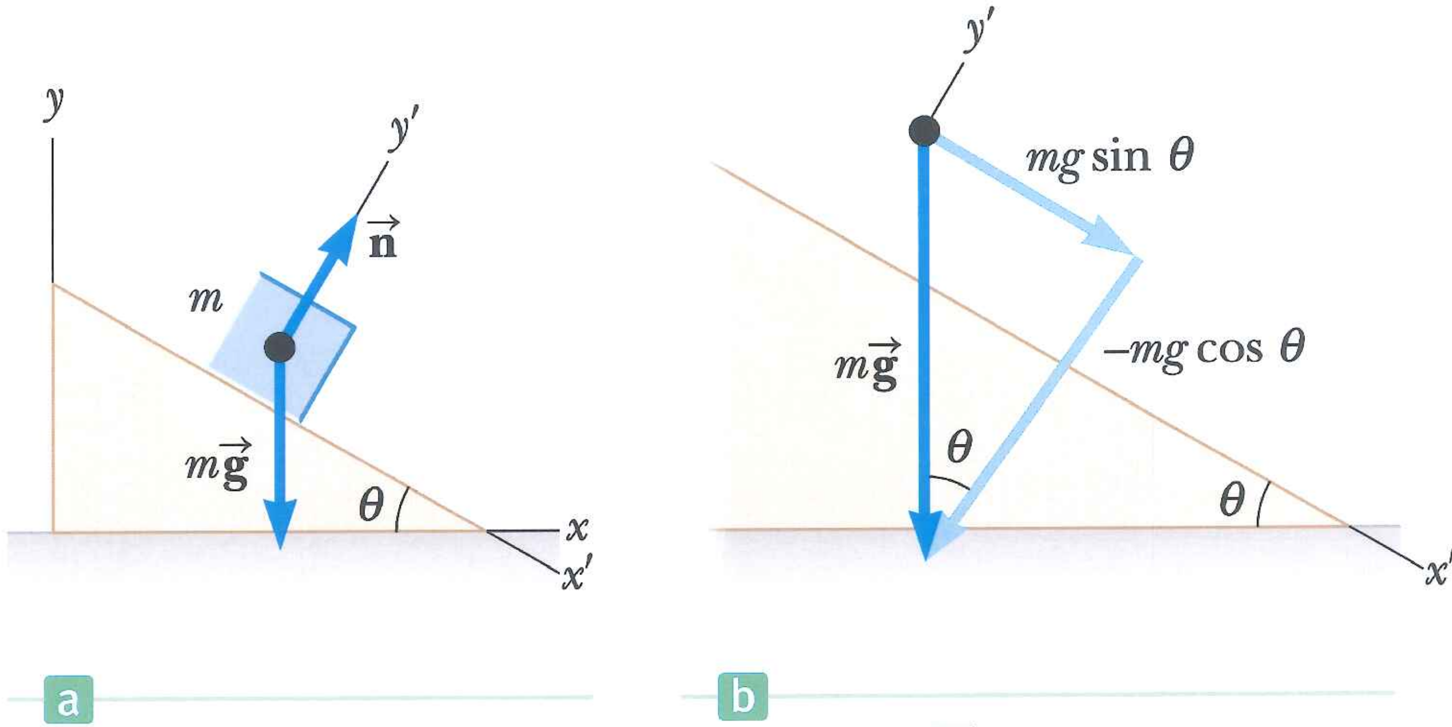
Sometimes it is more convenient to rotate the coordinate system.

For constant v,

$$\vec{F}_{net}=\vec{w}+\vec{n}+\vec{F}_f=0$$

$$\vec{F}_f=-\vec{w}\cdot\sin\theta \text{ and } \vec{N}=-\vec{w}\cdot\cos\theta$$

Case 4: The Normal Force on a Slope



$$F_{x', \text{grav}} = mg\sin\theta$$

$$F_{y', \text{grav}} = -mg\sin\theta$$

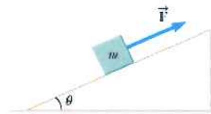
$$F_{y'} = -ma_{y'}$$

$$n - mg\cos\theta = 0$$

$$n = mg\cos\theta$$

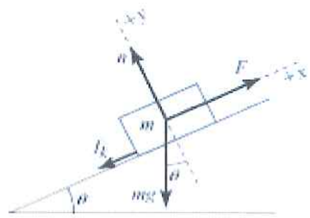
24. A block of mass $m = 5.8$ kg is pulled up a $\theta = 25°$ incline as in **Figure P4.24** with a force of magnitude $F = 32$ N.

Figure P4.24



a. Find the acceleration of the block if the incline is frictionless.

b. Find the acceleration of the block if the coefficient of kinetic friction between the block and incline is 0.10.



Because $a_y = 0$ for this block,

$$\Sigma F_y = n - mg\cos\theta = 0$$

and the normal force is $n = mg\cos\theta$.

(a) Since the incline is considered frictionless for this part, we take the friction force to be $f_k = 0$ and find

$$\Sigma F_x = F - mg\sin\theta = ma_x \qquad \text{or} \qquad a_x = \frac{F}{m} - g\sin\theta$$

giving $$a_x = \frac{32\text{ N}}{5.8\text{ kg}} - (9.8\text{ m/s}^2)\sin 25° = \boxed{1.4\text{ m/s}^2}$$

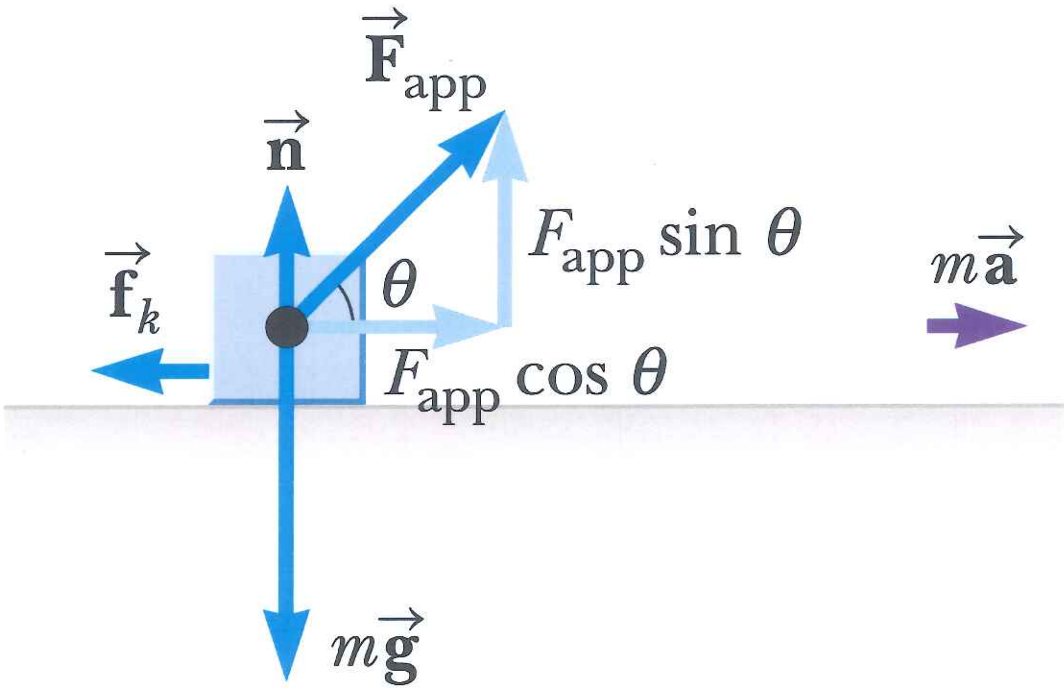
(b) If the coefficient of kinetic friction between the block and the incline is μ_k, then the friction force is $f_k = \mu_k n = \mu_k mg\cos\theta$, and

$$\Sigma F_x = F - f_k - mg\sin\theta = F - mg(\mu_k\cos\theta + \sin\theta) = ma_x$$

Thus, $$a_x = \frac{F}{m} - g(\mu_k\cos\theta + \sin\theta)$$

and $$a_x = \frac{32\text{ N}}{5.8\text{ kg}} - (9.8\text{ m/s}^2)[(0.10)\cos 25° + \sin 25°] = \boxed{0.49\text{ m/s}^2}$$

Newton's Third Law



$$n = mg - F_{app} \sin\theta$$

$$ma_x = F_{app,x} - f_k = F_{app} \cos\theta - \mu_k n$$

$$ma_x = F_{app} \cos\theta - \mu_k \left(mg - F_{app} \sin\theta\right)$$

The Force of Kinetic Friction

$$f_k = \mu_k n$$

μ_k is coefficient of kinetic friction

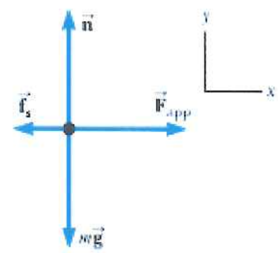
26. A man exerts a horizontal force of 125 N on a crate with a mass of 30.0 kg.

a. If the crate doesn't move, what's the magnitude of the static friction force?

b. What is the minimum possible value of the coefficient of static friction between the crate and the floor?

4.26 **(a)** To find the static friction force on the crate, apply the x-component of Newton's second law with $a_x = 0$. From the free-body diagram, two forces have x-components so that

$$\Sigma F_x = ma_x$$
$$F_{\text{app}} - f_s = 0$$
$$f_s = F_{\text{app}} = \boxed{125\ \text{N}}$$



(b) The minimum possible value of the coefficient of static friction is found using the relation $f_s \le \mu_s n$. From Section 4.3, Case 2 with $\theta = 0$, the normal force acting on the crate is $n = mg$ so that

$$f_s \le \mu_s mg$$
$$\mu_s \ge \frac{f_s}{mg} = \frac{125\ \text{N}}{(30.0\ \text{kg})(9.80\ \text{m/s}^2)}$$
$$\mu_{s,\text{min}} = \boxed{0.425}$$

Newton's Third Law

Table 4.2 Coefficients of Friction[a]

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

[a]All values are approximate.

22. A student of mass 60.0 kg, starting at rest, slides down a slide 20.0 m long, tilted at an angle of 30.0° with respect to the horizontal. If the coefficient of kinetic friction between the student and the slide is 0.120, find

a. the force of kinetic friction,

b. the acceleration, and

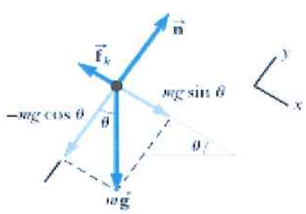
c. the speed she is traveling when she reaches the bottom of the slide.

4.22 **(a)** The force of kinetic friction is $f_k = \mu_k n$. From Section 4.3, Case 4, the normal force acting on the student is $n = mg\cos\theta$. Substitute this result to find

$$\begin{aligned} f_k &= \mu_k n = \mu_k mg\cos\theta \\ &= (0.120)(60.0\text{ kg})(9.80\text{ m/s}^2)\cos(30.0°) \\ &= \boxed{61.1\text{ N}} \end{aligned}$$

(b) Three forces act on the sliding student. Find her acceleration by drawing a free-body diagram with tilted coordinates and applying the x-component of Newton's second law:

$$\begin{aligned} \Sigma F_x &= ma_x \\ mg\sin\theta - f_k &= ma \end{aligned}$$



Solve for the acceleration a and substitute $f_k = \mu_k mg\cos\theta$ to find

$$\begin{aligned} a &= g[\sin\theta - \mu_k\cos\theta] = (9.80\text{ m/s}^2)[\sin(30.0°) - (0.120)\cos(30.0°)] \\ &= \boxed{3.88\text{ m/s}^2} \end{aligned}$$

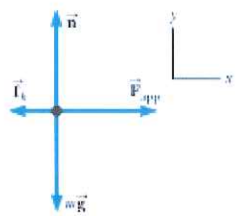
(c) To find her speed at the bottom of the slide, apply the time-independent kinematic equation with $v_0 = 0$:

$$\begin{aligned} v^2 &= v_0^2 + 2a\Delta x \\ v &= \sqrt{2(3.88\text{ m/s}^2)(20.0\text{ m})} = \boxed{12.5\text{ m/s}} \end{aligned}$$

20. A horizontal force of 95.0 N is applied to a 60.0-kg crate on a rough, level surface. If the crate accelerates at 1.20 m/s^2, what is the magnitude of the force of kinetic friction acting on the crate?

4.20 Four forces act on the crate. Use the free-body diagram to add all the x-components and apply Newton's second law:

$$\Sigma F_x = ma_x$$
$$F_{app} - f_k = ma$$



Solve for the kinetic friction force, f_k, and substitute values to find

$$f_k = F_{app} - ma$$

$$f_k = (95.0\text{ N}) - (60.0\text{ kg})(1.20\text{ m/s}^2)$$

$$f_k = \boxed{23.0\text{ N}}$$

Newton's Third Law