Ch. 4 Newton's Laws

Identity vs. Equation

- Math notation “=“ used often to denote both
- However, there is a big difference in between:
- **Identity** – means RHS of math relation DEFINES as LHS. There is a special notation for that type of equality: **“$\equiv$”**, i.e. they are **trivially equal**
- **Equation** – means LHS and RHS of math relation defined independently, but happen to have equal values, i.e. there are **none-trivially equal**. This is the case when sign **“=“** used properly.
- You should be able distinguish these too cases, if you try to stay rigorous.

Kinematics

- We introduced quantities: displacement, average velocity and average acceleration
- We introduced rates of change:
- $\mathbf{v}_{ave} \equiv \Delta\mathbf{r}/\Delta t$, $\mathbf{a}_{ave} \equiv \Delta\mathbf{v}/\Delta t$
- Now, if we assume $\mathbf{a}_{ave} =$ const, we will derive the whole set of formulas used in Ch. 2 & Ch. 3, without even introducing the **Calculus.**

Dynamics

- Can we actually introduce equations for

$$\mathbf{v}_{ave} = ?,\ \mathbf{a}_{ave} = ?$$

instead of identities we had in kinematics?

The answer is **yes**, but we need to tune-up math for that.

Calculus

- Developed by Newton and Leibnitz (circa 1660)

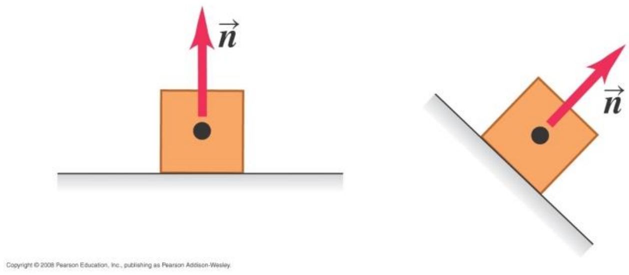
- **With Calculus we can actually connect formal math to the real world phenomena.**

Forces

- **The push and pull between bodies or a body and its surrounding represent physical quantity called FORCE.**

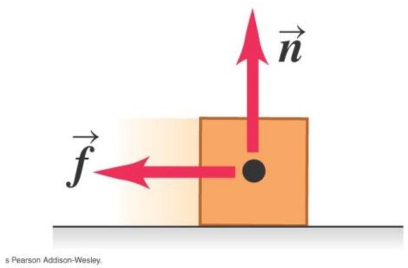
- **Two major categories of forces: contact and long-range forces**
- **Forces are vectors**
- **Units: measured in Newtons(N), in SI**

Contact Forces



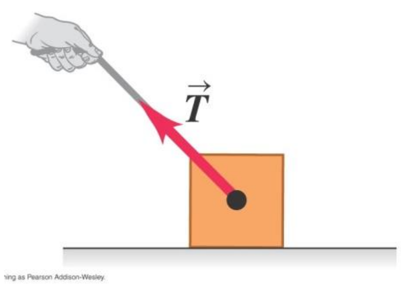
Normal force $\vec{n}$

For an object on a surface, the surface pushes back with a force <u>perpendicular</u> to the surface



Friction force $\vec{f}$

Acts <u>parallel</u> to the surface in the <u>opposite</u> direction of sliding.

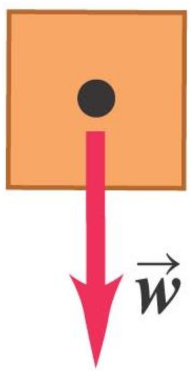


Tension force $\vec{T}$

Pulled force exerted on an object by a rope, cord, chain, etc.

Force acts along the rope.

Long-Range Forces



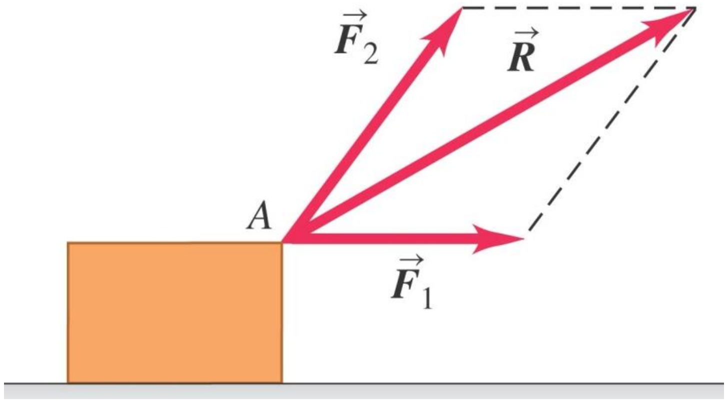
Weight $\vec{w}$

Gravitational force that the earth exerts on a body

(there are more, but you won’t see them until E&M)

Superposition of Forces

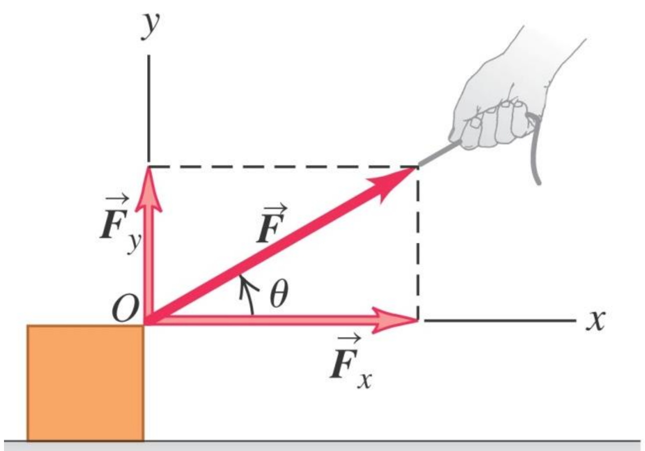
For two forces $\mathbf{F}_1$ and $\mathbf{F}_2$ acting on an object, the effect of motion is the same as that from a single force $\mathbf{R} = \mathbf{F}_1 + \mathbf{F}_2$.

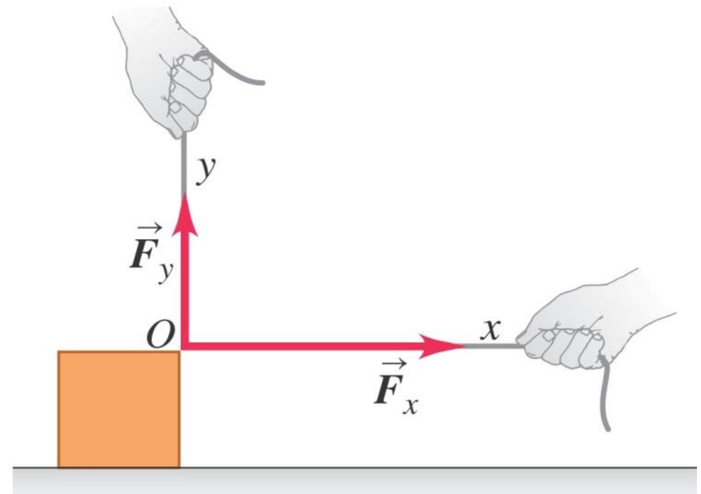


We can repeat this for any number of forces.

Superposition of Forces

Alternatively, we can deconstruct forces into their x and y components:





This is important because x and y components add easily. The net force **R** may be represented as:

$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots = \sum \vec{F}$$

Newton's First Law

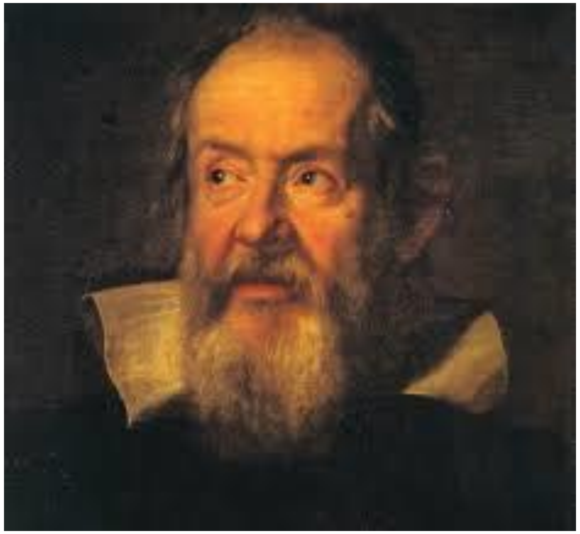
1. **If** $\sum \vec{F} = 0$

$$\Rightarrow \qquad \vec{v} = const$$

Newton's 1st Law (Law of Inertia): as long as net force acted on a body equal zero, a body will remain at rest or will keep moving with constant velocity.

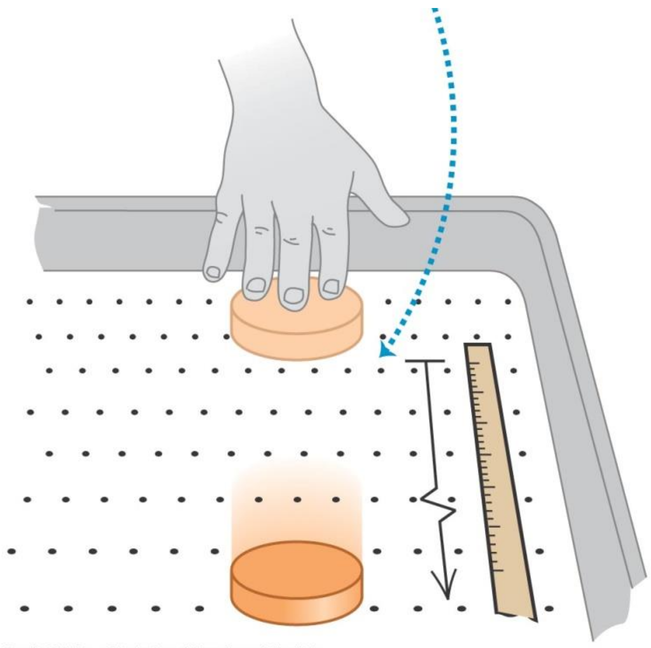
THIS IS ACTUALLY A PHYSICAL LAW
NOT JUST A MATHEMATICAL
ABSTRACTION, WHICH WE HAD IN KINEMATICS

Law of Inertia was first discovered by Galileo Galilei. Newton just reclaimed this law, based on its conceptual importance, as the 1st law of modern mechanics known as classical or Newtonian mechanics



Newton's First Law

Consider sliding a puck on an air hockey table.



It continues to slide at constant velocity until another force acts on it.

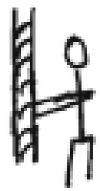
When $\sum \vec{F} = 0$

an object is said to be in equilibrium. Also:

$$\sum \vec{F} = 0 \Rightarrow \sum F_X = 0, \sum F_Y = 0, \sum F_Z = 0$$

Newton's 1st Law: none-inertial ref. frame

Say you are riding a DART train and balancing yourself by holding onto a pole.



While the train is moving at constant *v*, all is fine…

However, if the train stops quickly, you go flying…

No forces pushed you off the pole, so what about Newton's 1st law?

We need to consider your *frame of reference*

None-inertial frame, continued

When the DART is slowing down, your frame of reference is accelerating

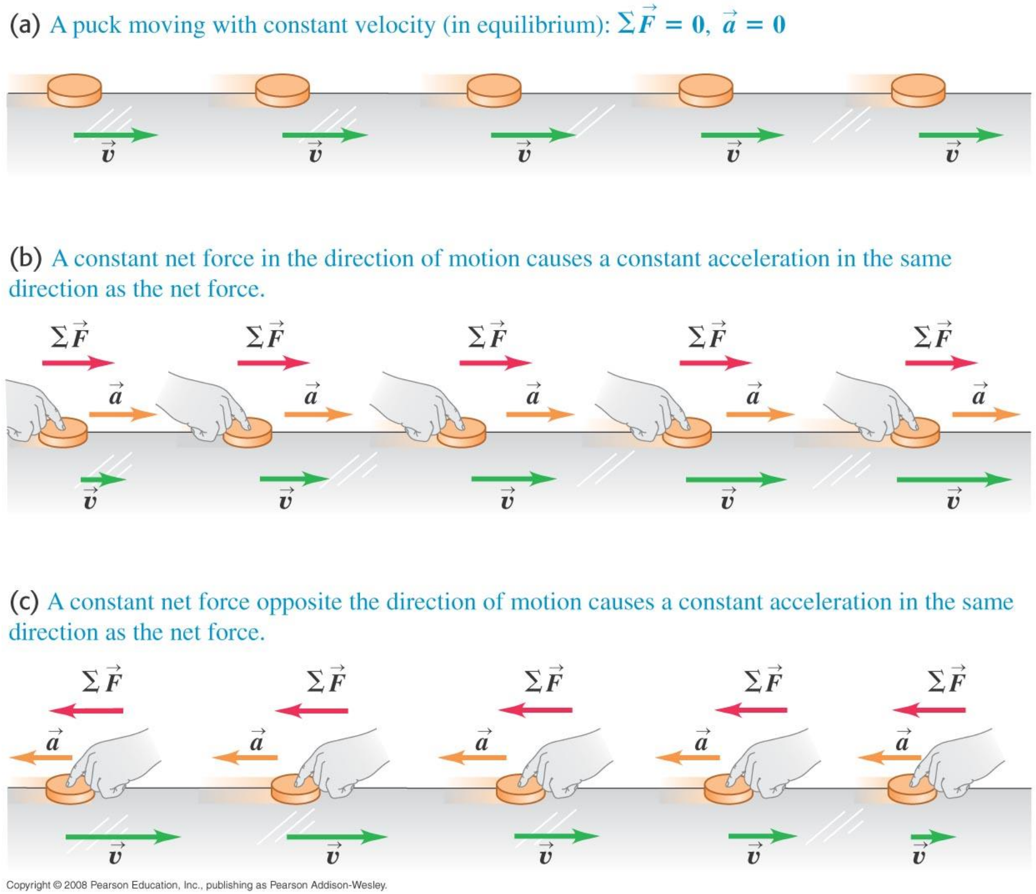
This is NOT a suitable reference frame for Newton's 1st law!

We need an **inertial frame of reference** for Newton's 1st…

For us, the **Earth's surface** can be considered for wide range of experiments as an inertial frame, and any frame moving with constant velocity with respect to this surface will also work. However, not always.

Newton’s Second Law

Consider again a puck on our air hockey table:



Newton's 2nd Law

$$\vec{a} = ?$$

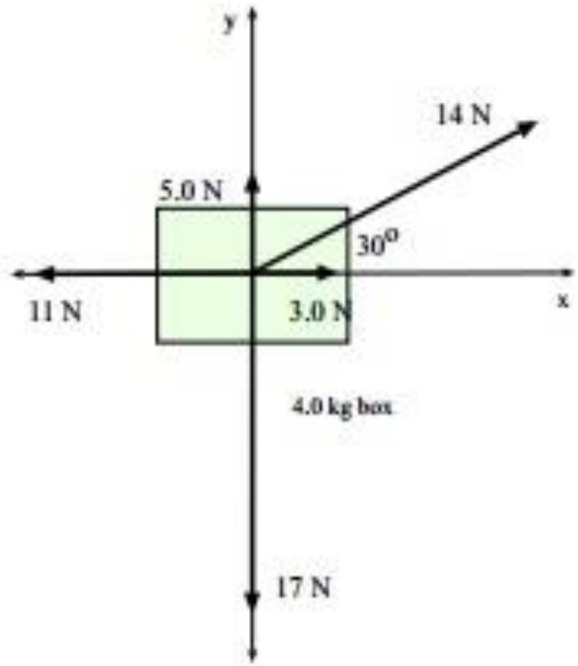
2. **If a nonzero net external force acts on a body, it accelerates. The direction of acceleration is the same as the direction of the net force. The magnitude of acceleration is equal the magnitude of net force divided by a universal scalar called a "mass"of the body.**

$$\vec{a} = \frac{\sum \vec{F}}{m} \qquad m = \frac{|\sum \vec{F}\,|}{|\,\vec{a}\,|} \qquad \sum \vec{F} = m\vec{a}$$

Mass & Force: details

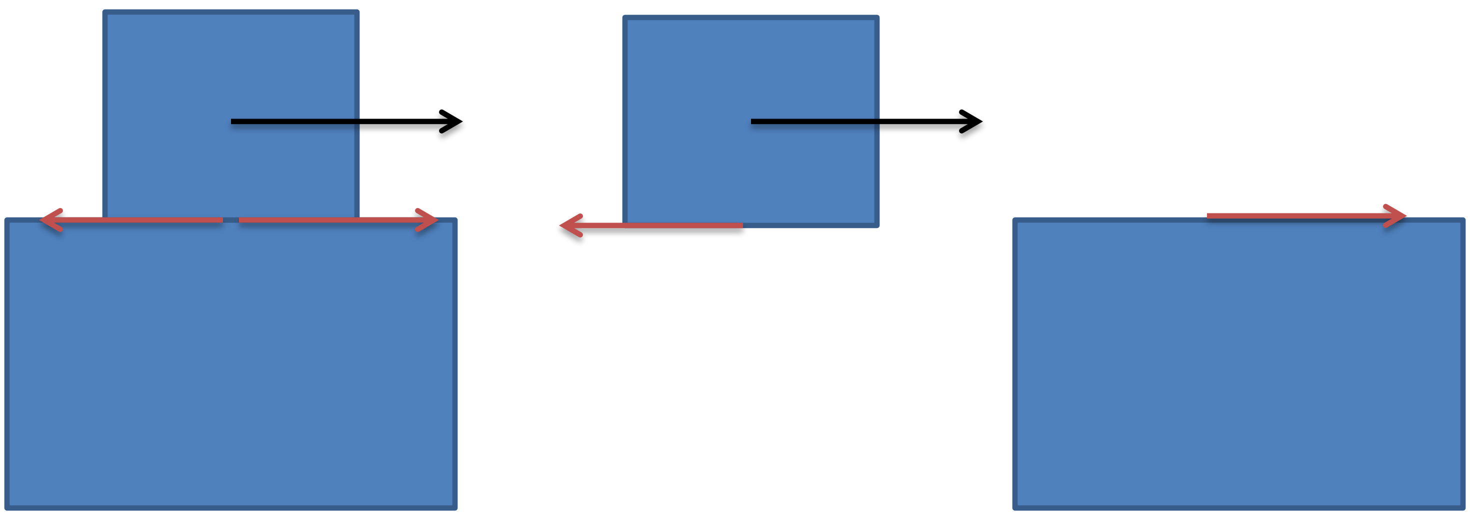
- The greater the mass, the harder it is to accelerate an object.
- The SI unit of mass is the kilogram (kg)
- The SI unit of force is a Newton
  - 1N-The force to accelerate a 1kg mass by 1 m/s^2
  - $1N = 1\ kg*m/s^2$.
- Mass is additive: if we put m_1 and m_2 together, the composite has mass m_1+m_2
- For the same force, the ratio of the masses of two bodies is the inverse of their accelerations.

4. Five forces pull on the 4.0 kg box in Fig. 4.1. Find the box's acceleration (a) in unit–vector notation and (b) as a magnitude and direction. [HRW5 5-9]



Free body diagrams

These are drawings showing a body free of its surroundings with vectors drawn to show the magnitudes and directions of forces acting on it.



This “not-free body” drawing is confusing

Newton's 3rd Law

If body A exerts a force on body B, then body B exerts a force on body A. These two forces have the same magnitude but are opposite in direction. These two forces act on different bodies.

$$\vec{F}_{A\to B} = -\vec{F}_{B\to A}$$

7. Find the tension in each cord for the systems shown in Fig. 4.2. (Neglect the mass of the cords.) [Ser4 5-26]

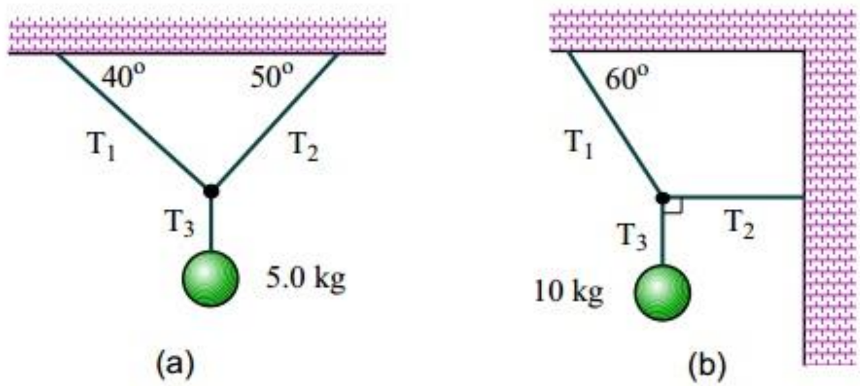


Figure 4.2: Masses suspended by strings, for Example 7.

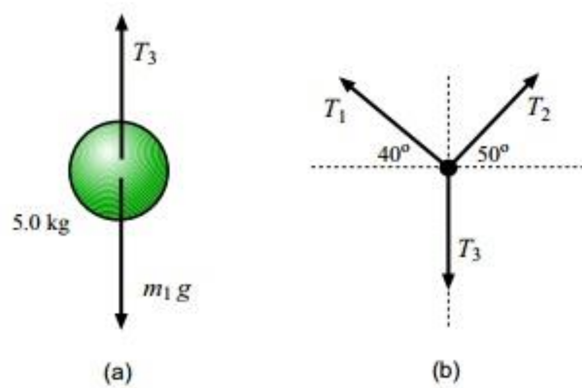
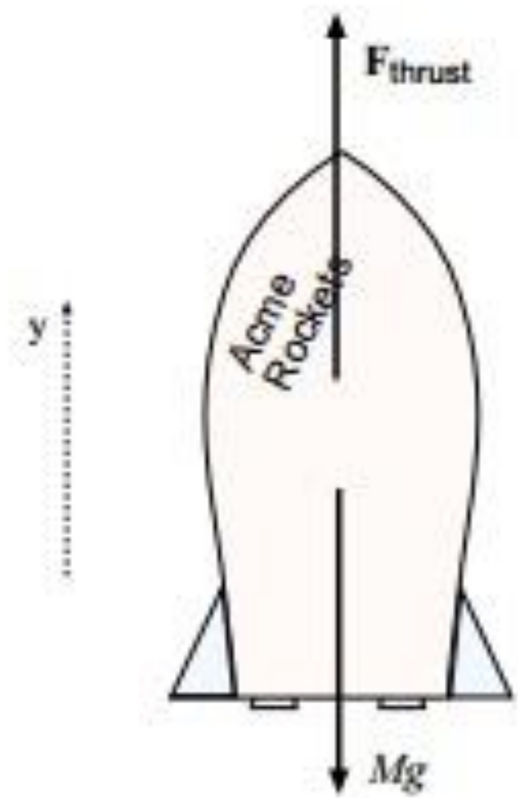
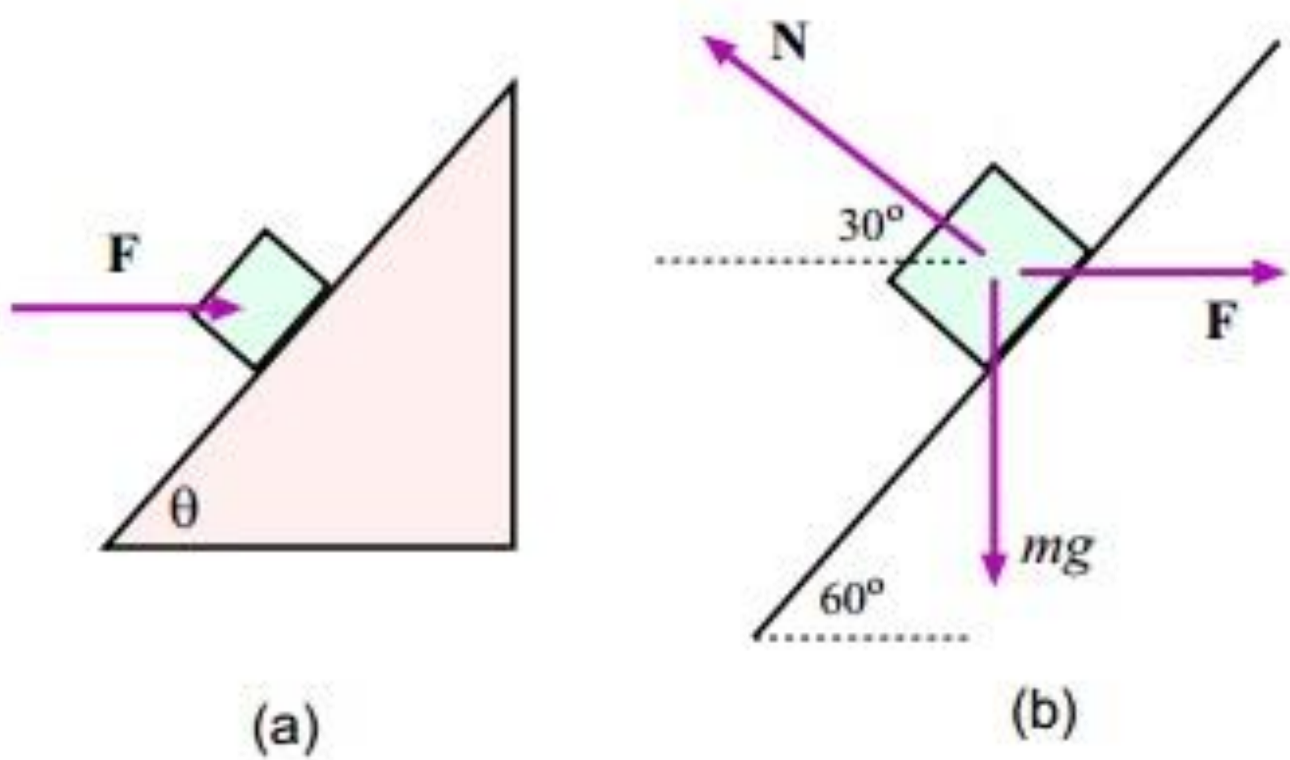


Figure 4.3: Force diagrams for part (a) in Example 7.

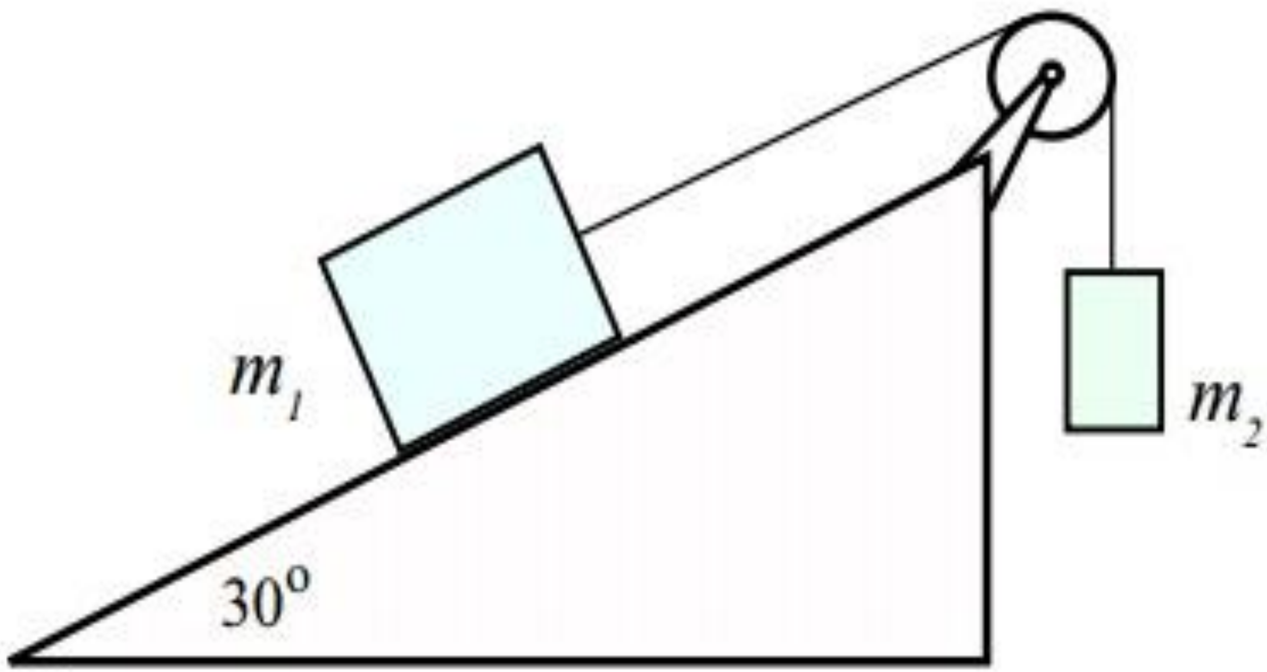
9. A rocket and its payload have a total mass of $5.0 \times 10^4\,\text{kg}$. How large is the force produced by the engine (the thrust) when (a) the rocket is "hovering" over the launchpad just after ignition, and (b) when the rocket is accelerating upward at $20\,\frac{\text{m}}{\text{s}^2}$? [HRW5 5-35]



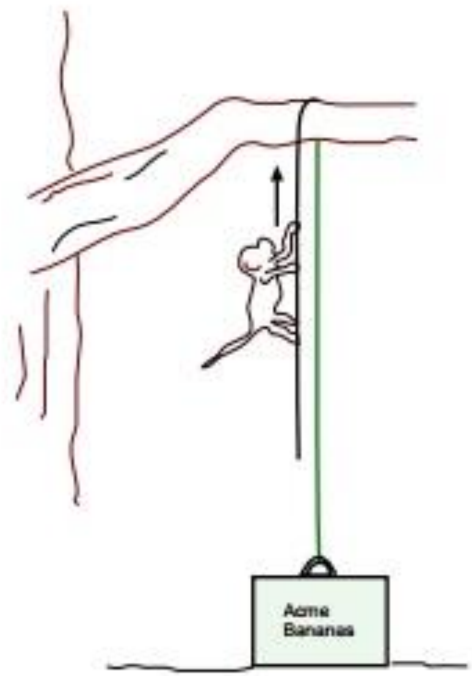
10. A block of mass $m = 2.0\,\mathrm{kg}$ is held in equilibrium on an incline of angle $\theta = 60°$ by the horizontal force F, as shown in Fig. 4.5(a). (a) Determine the value of F, the magnitude of F. (b) Determine the normal force exerted by the incline on the block (ignore friction). [Ser4 5-33]



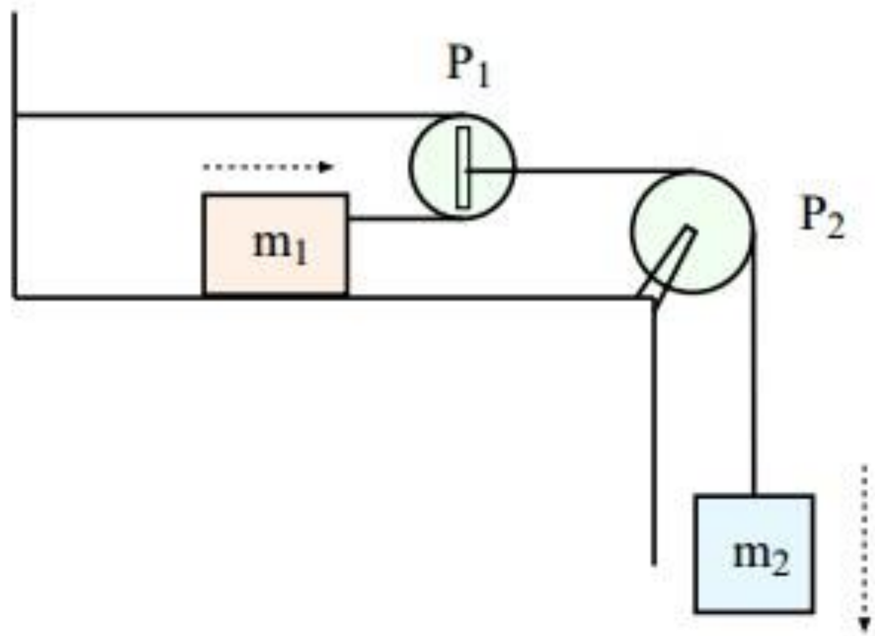
11. A block of mass $m_1 = 3.70\,\mathrm{kg}$ on a frictionless inclined plane of angle $\theta = 30.0°$ is connected by a cord over a massless, frictionless pulley to a second block of mass $m_2 = 2.30\,\mathrm{kg}$ hanging vertically, as shown in Fig. 4.6. What are (a) the magnitude of the acceleration of each block and (b) the direction of the acceleration of m_2? (c) What is the tension in the cord? [HRW5 5-58]



12. A 10 kg monkey climbs up a massless rope that runs over a frictionless tree limb (!) and back down to a 15 kg package on the ground, as shown in Fig. 4.9. (a) What is the magnitude of the least acceleration the monkey must have if it is to lift the package off the ground? If, after the package has been lifted the monkey stops its climb and holds onto the rope, what are (b) the monkey's acceleration and (c) the tension in the rope? [HRW5 5-64]



14. Mass m_1 on a frictionless horizontal table is connected to mass m_2 through a massless pulley P_1 and a massless fixed pulley P_2 as shown in Fig. 4.13. (a) If a_1 and a_2 are the magnitudes of the accelerations of m_1 and m_2 respectively, what is the relationship between these accelerations? Find expressions for (b) the tensions in the strings and (c) the accelerations a_1 and a_2 in terms of m_1, m_2 and g. [Ser4 5-46]



Mass vs. Weight

Mass	Weight
Not a force	Is a force
Independent of *g*	Depends on *g*
$m=F/a$	$\mathbf{w}=m\mathbf{g}$
Large m is hard to accelerate	Large w is hard to lift against g

- A 1 kg mass has a 9.8 N weight on earth. The same object has a 1 kg mass on the moon but a 1.6 N weight.
- Weight acts at all times, even if an object is not falling
- Weight does not change in freefall
- Weight changes with location as gravity varies.

Don’t get confused

We often talk about weight as in pounds or kilograms.

- **A pound-force is a unit of force (lbf):**

$$\mathbf{1N \approx 0.22481\ lbf}$$

- **A kilogram-force is a unit of force as well (kilopond, kp)**:

$$\mathbf{1N \approx 0.10197\ kp}$$

- **When we say something “weighs x kg”, we really mean quantity in kilogram-force units, NOT in kilogram units of mass.**

Ch. 4

End