Homework 2   Forces

1. Two identical particles each with mass $m = 1.0\ kg$ are a distance $l = 0.5\ m$ apart. What is the magnitude of the gravitational force exerted by one particle on the other one?

2. Estimate the gravitational force you exert on a person a distance $l = 1.0\ m$ away (your lab partner?). Clearly state the assumptions you make and how you estimate the values you used in your calculation.

3. For a satellite orbiting at an altitude of $h = 200\ km$ above the Earth's surface, what is the magnitude of the acceleration of gravity?

4. In a thundercloud, there may be an electric charge $q_t = 10\ C$ near the top of the cloud and the opposite charge $q_b = -10\ C$ at the bottom of the cloud. The charge are separated by a $r_c = 1.5\ km$. What is the magnitude of the electric force exerted on each charge?

5. An astronaut is orbiting the Earth and docking with a communications satellite. The satellite is in an orbit 650 km above the Earth's surface where the free-fall acceleration is $a = 8.09\ m/s^2$. What is the satellite's speed?

6. Because the Earth rotates about its axis, a point on the equator experiences a centripetal acceleration of $a_e = 0.0337\ m/s^2$ whereas a point at the poles experiences no centripetal acceleration. Assume the Earth is a uniform sphere with $g = 9.800\ m/s^2$. (a) Show that at the equator the gravitational force on an object must exceed the normal force required to support the object. (b) If a person at the equator has a mass $m = 80\ kg$ what is the gravitational force on the person? (c) What is the normal force on the person? (d) Do your results agree with part (a)?

7. Two forces, $\vec{F}_1 = (-6\hat{i} - 4\hat{j})N$ and $\vec{F}_2 = (-3\hat{i} + 7\hat{j})N$, act on a particle of mass 2.00 kg that is initially at rest at coordinates $(-2.00\ m, +4.00\ m)$. (a) What are the components of the particles velocity at $t = 10.0\ s$? (b) In what direction is the particle moving at $t = 10.0\ s$? (c) What displacement does the particle undergo during the first 10.0 s? (d) What are the coordinates of the particle at $t = 10.0\ s$?

8. To model a spacecraft, a toy rocket engine is securely fastened to a large puck that can glide with negligible friction over a horizontal surface, taken as the xy plane. The 4.00-kg puck has a velocity of $3.00\hat{i}\ m/s$ at one instant. Eight seconds later, its velocity is to be $(8.00\hat{i} + 10.0\hat{j})\ m/s$. Assuming that the rocket engine exerts a constant horizontal force, find (a) the components of the force and (b) its magnitude.

9. Two forces $\vec{F}_1$ and $\vec{F}_2$ act on a 5.00-kg object. If $F1 = 20.0\ N$ and $F_2 = 15.0\ N$, find the accelerations in (a) and (b) of the figure.
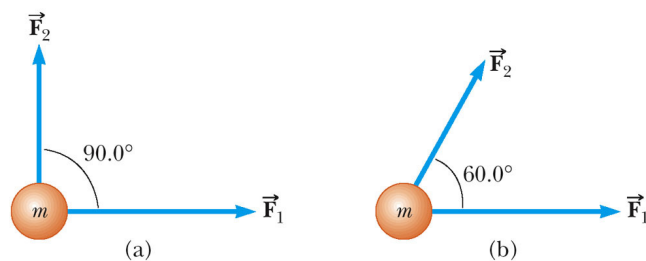

10. Three forces, given by $\vec{F}_1 = (2.00\hat{i} + 2.00\hat{j})\ N$, $\vec{F}_2 = (5.00\hat{i} - 3.00\hat{j})\ N$, and $\vec{F}_3 = (-45.0\hat{i})N$, act on an object to give it an acceleration of magnitude $3.75\ m/s^2$. (a) What is the direction of the acceleration? (b) What is the mass of the object? (c) If the object is initially at rest, what is its speed after 10.0 s? (d) What are the velocity components of the object after 10.0 s?

11. An electron of mass $9.11 \times 10^{-31}\ kg$ has an initial speed of $3.00 \times 10^5\ m/s$. It travels in a straight line, and its speed increases to $7.00 \times 10^5\ m/s$ in a distance of 5.00 cm. Assuming that its acceleration is constant, (a) determine the net force exerted on the electron and (b) compare this force with the weight of the electron.

12. You stand on the seat of a chair and then hop off. (a) During the time you are in flight down to the floor, the Earth is lurching up toward you with an acceleration of what order of magnitude? In your solution, explain your logic. Model the Earth as a perfectly solid object. (b) The Earth moves up through a distance of what order of magnitude?

13. The average speed of a nitrogen molecule in air is about 6.70×10^2 m/s, and its mass is 4.68×10^{-26} kg. (a) If it takes 3.00×10^{-13} s for a nitrogen molecule to hit a wall and rebound with the same speed but moving in the opposite direction, what is the average acceleration of the molecule during this time interval? (b) What average force does the molecule exert on the wall?

14. A $7.0 - kg$ block rests on the floor. (a) What force does the floor exert on the block? (b) A rope is tied to the block and is run vertically over a pulley. The other end of the rope is attached to a free-hanging $4 - kg$ weight. What is the force exerted by the floor on the $7.0 - kg$ block?

15. A simple accelerometer is constructed inside a car by suspending an object of mass m from a string of length L that is tied to the cars ceiling. As the car accelerates the string object system makes a constant angle of θ with the vertical. (a) Assuming that the string mass is negligible compared with m, derive an expression for the cars acceleration in terms of θ and show that it is independent of the mass m and the length L. (b) Determine the acceleration of the car when $\theta = 23.0°$.

16. A bag of cement of weight F_g hangs in equilibrium from three wires as shown in the figure. Two of the wires make angles θ_1 and θ_2 with the horizontal. Show that the tension T_1 in the left-hand wire is

$$T_1 = \frac{F_g \cos \theta_2}{\sin(\theta_1 + \theta_2)}$$
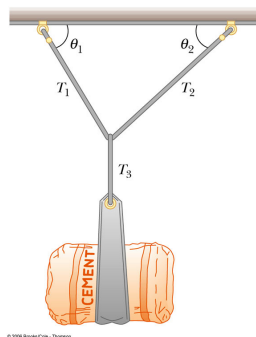
17. Two people pull as hard as they can on horizontal ropes attached to a boat that has a mass of 200 kg. If they pull in the same direction, the boat has an acceleration of 1.52 m/s^2 to the right. If they pull in opposite directions, the boat has an acceleration of 0.518 m/s^2 to the left. What is the magnitude of the force each person exerts on the boat? Disregard any other horizontal forces on the boat.

18. A 1.00-kg object is observed to accelerate at 10.0 m/s^2 in a direction 30.0° northeast as shown in the figure. The force $\vec{F_2}$ acting on the object has magnitude 5.00 N and is directed north. What is the magnitude and direction of the force $\vec{F_1}$ acting on the object.
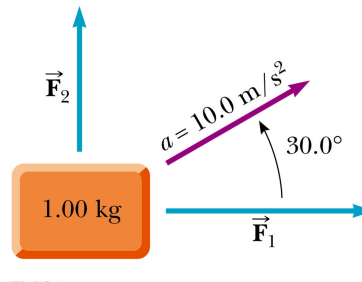

19. A 25.0-kg block is initially at rest on a horizontal surface. A horizontal force of 75.0 N is required to set the block in motion. After it is in motion, a horizontal force of 60.0 N is required to keep the block moving with constant speed. Find the coefficients of static and kinetic friction from this information.

20. To meet a U.S. Postal Service requirement, footwear must have a coefficient of static friction of 0.4 or more on a specified tile surface. A typical athletic shoe has a coefficient of 0.800. In an emergency, what is the minimum time interval in which a person starting from rest can move 1.5 m on a tile surface if she is wearing (a) footwear meeting the Postal Service minimum and (b) a typical athletic shoe?

21. To determine the coefficients of friction between rubber and various surfaces, a student uses a rubber eraser and an incline. In one experiment, the eraser begins to slip down the incline when the angle of inclination

is 32.0° and then moves down the incline with constant speed when the angle is reduced to 27.0°. From these data, determine the coefficients of static and kinetic friction for this experiment.

22. A woman at an airport is towing her 20.0-kg suitcase at constant speed by pulling on a strap at an angle θ above the horizontal as shown in the figure. She pulls on the strap with a 35.0-N force, and the friction force on the suitcase is 20.0 N. Draw a free-body diagram of the suitcase. (a) What angle does the strap make with the horizontal? (b) What normal force does the ground exert on the suitcase?

23. Two identical isolated particles, each of mass 2.00 kg, are separated by a distance of 30.0 cm. What is the magnitude of the gravitational force exerted by one particle on the other?

24. Find the order of magnitude of the gravitational force that you exert on another person 2 m away. In your solution, state the quantities you measure or estimate and their values.

25. A light string can support a stationary hanging load of 25.0 kg before breaking. A 3.00-kg object attached to the string rotates on a horizontal, frictionless table in a circle of radius 0.800 m, and the other end of the string is held fixed. What range of speeds can the object have before the string breaks?

26. A crate of eggs is located in the middle of the flatbed of a pickup truck as the truck negotiates an unbanked curve in the road. The curve may be regarded as an arc of a circle of radius 35.0 m. If the coefficient of static friction between crate and truck is 0.600, how fast can the truck be moving without the crate sliding?

27. Consider a conical pendulum with an 80.0-kg bob on a 10.0-m wire making an angle $\theta = 5.00°$ with the vertical as as shown in the figure. What are (a) the horizontal and vertical components of the force exerted by the wire on the pendulum and (b) the radial acceleration of the bob.
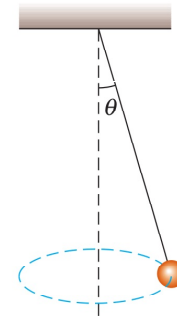
28. You are riding in a car that is going around a flat curve that has a radius of 50.0 m from the middle of the car to the center of curvature. A good-luck charm that is hanging from a 0.3-m long string from the rear-view mirror has a mass $m = 0.1$ kg. The string makes an angle $\theta = 35.0°$ to the vertical. What is the speed v of the car?

29. Imagine a landing craft approaching the surface of Callisto, one of Jupiter's moons. If the engine provides an upward force $F_1 = 3000$ N, the craft descends at a constant speed. If the engine only provides an upward force $F_2 = 2500$ N, the craft accelerates downward at $a_2 = -0.4$ m/s^2. (a) What is the magnitude of the free-fall acceleration at the surface of Callisto? (b) What is the mass of the landing craft?

30. When a falling meteor is at a distance above the Earths surface of 3.00 times the Earths radius, what is its free-fall acceleration caused by the gravitational force exerted on it?

31. In a thundercloud, there may be electric charges of $+40.0$ C near the top of the cloud and -40.0 C near the bottom of the cloud. These charges are separated by 2.00 km. What is the electric force on the top charge?

32. Because the Earth rotates about its axis, a point on the equator experiences a centripetal acceleration of $0.0337 m/s^2$, whereas a point at the poles experiences no centripetal acceleration. (a) Show that at the equator the gravitational force on an object must exceed the normal force required to support the object. That is, show that the objects true weight exceeds its apparent weight. (b) What is the apparent weight at the equator and at the poles of a person having a mass of 75.0 kg? (Assume that the Earth is a uniform sphere and take $g = 9.800 m/s^2$.)

33. An amusement park ride called the Rotor is made of a large vertical cylinder that spins fast enough so the people inside are pinned against the wall when the floor drops away as shown in the figure. Let μ_s be the coefficient of static friction between a person and wall, and the radius of the cylinder is R. (a) Show the maximum time or period of revolution T necessary to keep a person from falling is $T = 2\pi\sqrt{\mu_s R/g}$. (b) What is the value of T assuming that $R = 3.0 \ m$ and $\mu_s = 0.400$. How many revolutions per minute does the cylinder make?
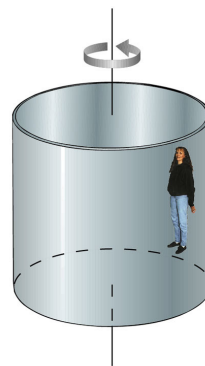
34. Three uniform spheres of mass 2.00 kg, 4.00 kg, and 6.00 kg are placed at the corners of a right triangle as shown below. Calculate the resultant gravitational force on the 4.00-kg object, assuming that the spheres are isolated from the rest of the Universe.
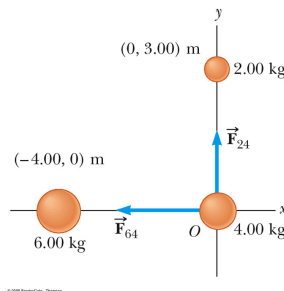
35. The free-fall acceleration on the surface of the Moon is about one-sixth that on the surface of the Earth. Assuming that the radius of the Moon is about $0.250 R_E$, what is the ratio of their average densities, ρ_{Moon}/ρ_{Earth} .

36. The space shuttle is in a high, circular orbit a distance h_1 above the surface of the Earth. The crew performs an experiment that needs to take place far away from the spacecraft so a payload of mass m_1 is 'lowered' toward the Earth on a massless rope of length h_2. The shuttle and the payload are flying along in equilibrium so the spacecraft, the payload, and the rope are all aligned along a radius from the center of the Earth to the shuttle. The period of the shuttle's orbit T_s is known, the mass m_1 of the payload is much smaller than the shuttle mass and $h_2 << h_1$. How is the shuttle's period T_s related to the payload's period T_p? What is the tension F_{rope} in the rope in terms of T_s, h_1, h_2, m_1 and any other known constants? Be careful with the notation because we sometimes use T to refer to tension and the period of the orbit.

37. A portion of Miranda, one of Uranus's moons, is shown in the figure. This moon can be modeled as a sphere of radius $242 \ km$ and mass $6.68 \times 10^{19} \ kg$. (a) What is the free-fall acceleration on its surface? (b) A cliff on Miranda called Verona Rupes is $5000 \ m$ high. It is marked by the arrow in the figure. If an extreme sports athlete runs horizontally off the top of the cliff at $8.50 \ m/s$, for what time interval will they be in flight? (Or will he or she be in orbit?) (c) How far from the base of the vertical cliff will they strike the icy surface of Miranda? (d) What will be their velocity vector when they hit?

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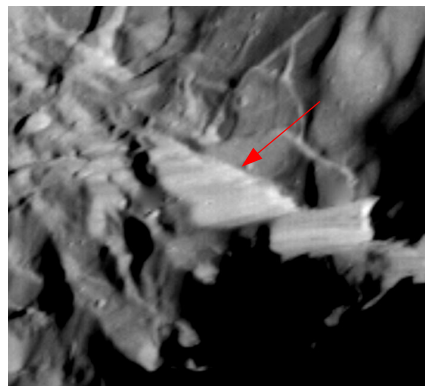
38. A spacecraft in the shape of a long cylinder has a length of 100 m, and its mass with occupants is 1000 kg. It has strayed too close to a black hole having a mass 100 times that of the Sun. The nose of the spacecraft points toward the black hole, and the distance between the nose and the center of the black hole is 10.0 km. See the figure. (a) Determine the total force on the spacecraft. Treat the spacecraft as if all the mass is concentrated at its center. (b) What is the difference in the gravitational fields acting on the occupants in the nose of the ship and on those in the rear of the ship, farthest from the black hole? This difference in accelerations grows rapidly as the ship approaches the black hole. It puts the body of the ship under extreme tension and eventually tears it apart.
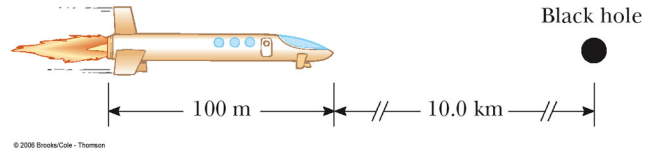
39. If the satellites of Saturn were created by 'accreting' dust, then their orbital periods should exceed the period for dust orbiting at the Roche limit which is 1.028×10^8 m for Saturn. What is the acceleration of gravity for dust or any other object orbiting at the Roche limit? What is the period for dust orbiting Saturn at the Roche limit? How does your result compare with the orbital period of Saturn's closest moon which is 5.0×10^4 s? The mass of Saturn is $M_S = 5.7 \times 10^{26}$ kg.

40. At the end of their life cycles many stars form a dense object called a neutron star with a mass equal to that of the Sun but with a radius of only 10^4 m. What is the gravitational acceleration at the surface of such a star? How fast would an object be moving if it fell for a period of 1.0 s at the star's surface?

41. Mount Everest is the highest mountain on the Earth at 29,028 feet. It's height was measured in 1852 by surveyors using telescopes from over one hundred miles away who were able to correct for effects like curvature of the Earth. Another effect to consider is a deviation from the line the surveyors used to determine the vertical direction and to measure angles. The vertical is defined with a plumb bob; a pointed piece of metal hung from a surveyor's telescope to establish a 'vertical' line. Usually, one assumes the plumb bob (like any other hanging object) points straight down, but this is not completely true on the rotating Earth. Consider the figure which shows a surveyor at a latitude of θ on the Earth's surface. What is the deviation of the plumb bob from the vertical if $\theta = 40°$? A person standing at a latitude of $40°$ moves in a circle of radius $r = 4.88 \times 10^6$ m at a speed of 355 m/s. You might find the following trigonometric identity useful.


$$\tan\theta = \frac{\sin\theta}{\cos\theta}$$
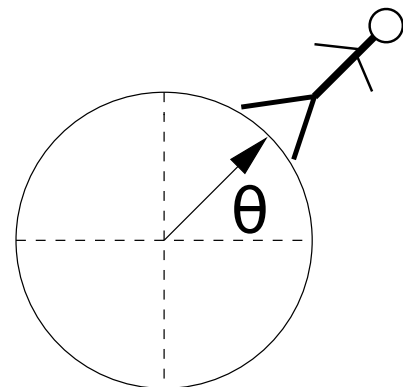
Do you think the effect is significant?

42. What is Roche's limit for Jupiter? What is the distance to Jupiter's nearest regular satellite?

43. What is the Roche limit for Earth? The International Space Station orbits the Earth at an altitude of approximately 409 km. Is it inside the Earth's Roche limit? If so, why isn't it torn apart?

44. What is the Roche limit for the Sun? Are there any planets inside the Sun's Roche limit? If so, why aren't they torn apart?

45. In deriving the equation for ΔF we used the fact that $d >> D$ where d is the distance from Saturn to the midpoint between the dust grains and D is the diameter of each dust grain. Show this approximation leads to

$$\frac{1}{(d - \frac{D}{2})^2} - \frac{1}{(d + \frac{D}{2})^2} = \frac{2dD}{(d - \frac{D}{2})^2(d + \frac{D}{2})^2} \approx \frac{2D}{d^3} \quad .$$

Saturn (M_S)

D

2 1

Dust grains (m_d)

d
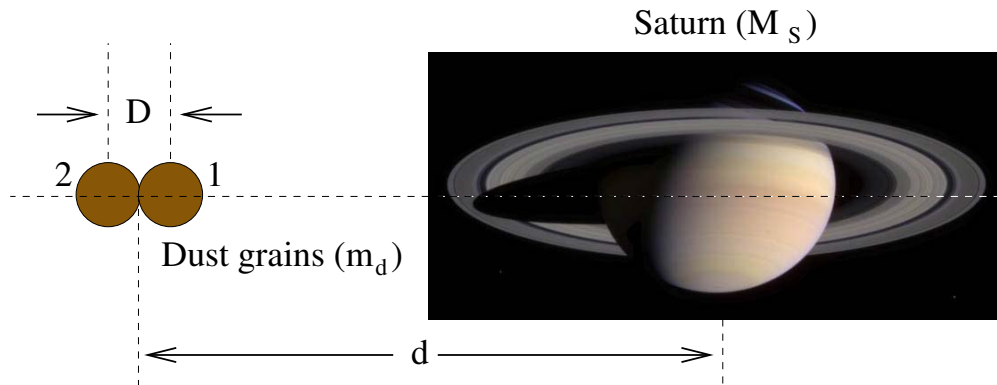
46. You are a recent Richmond physics graduate and get this cool job working for an outdoor recreation equipment company. Your boss is getting a sales pitch for a new bungee jumping system. Model the bungee cord as a spring. The parameters are $h = 267\ m$ where h is the height of the bridge, $\mathcal{L} = 50\ m$ is the unstretched length of the bungee cord and $k = 10\ N/m$ is its spring constant. If you buy it, will your customers survive?

47. In 1971 the Apollo 14 moon mission explored the Fra Mauro region of the Moon. During one moon walk astronaut Alan Shepard used a modified lunar excavation tool with a golf club head attached to it to 'play' golf on the moon. According to his report he hit one golf ball a distance of about $x_f = 200\ m$. Assume the ground was level and the initial velocity $\vec{v}_i$ made an angle $\theta = 35°$ with the ground. What was the initial velocity of the ball on the Moon? Start your solution from the equations of motion for two-dimensional, projectile motion (*i.e.* the equations for x, y, v_x, and v_y as functions of time t) and find an expression for the initial velocity. Compare your result with the typical ball speed of pro golfers of 80 m/s. The acceleration of gravity on the Moon is $a_M = 1.62\ m/s^2$.