GRAVITY & WEIGHT

Gravitational Force, Gravitational Field and Weight

1. A gravitational force…
   - A only exists between two very large objects like planets
   - B only exists between a small object and a very large object like a planet
   - C only exists between any two objects with different mass
   - D exists between any two objects with mass

2. Which of the following are valid units of weight? (select all that apply)
   - A kg
   - B kg·m/s²
   - C N
   - D N·m

3. In which of the following scenarios is the gravitational force between two objects an attractive force (the force on each object acts towards the other object)? (select all that apply)
   - A Both objects have the same mass
   - B One object has significantly more mass than the other
   - C The less massive object is positioned above the more massive object
   - D The more massive object is positioned above the less massive object

4. The gravitational force between two objects depends on… (select all that apply)
   - A the mass of the first object
   - B the distance between the center of each object
   - C the mass of the second object
   - D the radius of each object

5. A small object is sitting at rest on the ground. The gravitational force exerted by the object on the earth is…
   - A not related to the weight of the object
   - B greater than the weight of the object
   - C equal in magnitude to the weight of the object
   - D less than the weight of the object

6. Two objects attract each other with a gravitational force of magnitude F_{g1}. If the distance between the centers of each object was increased to be three times the original distance, what would be the new magnitude of the gravitational force?
   - A F_{g1}
   - B $3F_{g1}$
   - C $F_{g1}/3$
   - D $F_{g1}/9$

7. A block is sitting at rest on a table. The magnitude of the force exerted on the block by the earth is...
   - A less than the magnitude of the force exerted on the earth by the block
   - B equal to the magnitude of the force exerted on the earth by the block
   - C greater than the magnitude of the force exerted on the earth by the block
   - D not related the magnitude of the force exerted on the earth by the block

8. If the mass of the earth remained the same but the radius of the earth doubled, the gravitational force exerted on the moon by the earth would be...
   - A the same as its current magnitude
   - B twice its current magnitude
   - C one half of its current magnitude
   - D one fourth of its current magnitude

9. A ball of mass m_1 is dropped from some height and is falling through the air. The weight of the ball is…
   - A $m_1 g$
   - B m_1
   - C Gm_1
   - D $Gm_1 m_{earth}$

10. Each planet orbits the sun in an elliptical orbit, which means the distance between the planet and the sun changes as it moves around its orbit. The magnitude of the force exerted on a planet by the sun is greatest when...
    - A the planet is farthest from the sun
    - B the planet is closest to the sun
    - C the gravitational force is the same at every point in the orbit
    - D cannot be determined

11. A small object is near a very large building, but the object remains at rest. Why doesn't the object accelerate towards the building instead of remaining at rest?
    - A The building does not exert a force on the object
    - B There is a force acting on the object caused by the building which points towards the building, but there is an equal and opposite force acting on the object caused by the building which points away from the building
    - C The forces between the object and the building are equal and opposite so they cancel each other
    - D There is a force acting on the object caused by the building which points towards the building, but there is another force(s) acting on the object which points away from the building

12. Planet A and planet B have masses of m_A and m_B and the distance between their centers is r_1. If the mass of planet A is doubled and the mass of planet B is tripled, what would the new distance between their centers have to be (in terms of r_1) for the gravitational force between the planets to remain the same?
    - A $6r_1$
    - B $r_1/6$
    - C $\sqrt{6}r_1$
    - D none of the above

13. Objects A, B and C have different masses and are different distances from object D. Object A has a mass of 2 kg and its center is 3 m away from the center of object D. Object B has a mass of 10 kg and its center is 8 m away from the center of object D. Object C has a mass of 6 kg and its center is 4 m away from object D. How do the forces exerted on object D by each of the other objects compare?

A $F_A < F_C < F_B$
B $F_B < F_A < F_C$
C $F_B < F_C < F_A$
D $F_A < F_B < F_C$

14. Which of the following is required for a gravitational field to exist?

A Two objects with different masses
B Two objects with any mass
C One object with a large mass
D One object with any mass

15. A book is resting on a table. Which of the following statements are true? (select all that apply)

A The book produces a gravitational field around it due to its mass, and the earth is in that gravitational field so it experiences a gravitational force towards the book
B The earth produces a gravitational field around it due to its mass, and the book is in that gravitational field so it experiences a gravitational force towards the earth
C The earth and the book both have mass so they attract each other with a gravitational force
D The gravitational force exerted on the book by the earth is greater in magnitude than the gravitational force exerted on the earth by the book

16. The variable g represents... (select all that apply)

A the acceleration due to gravity
B the magnitude of the gravitational force
C the universal gravitational constant
D the strength of a gravitational field

17. Object A has a mass of m_A and a radius of R_A. Object B has a mass of $3m_A$ and a radius of $2R_A$. At a point in space that is the same distance from the centers of objects A and B, how do the strengths of the gravitational fields from each object compare?

A $g_B = g_A$
B $g_B = 3g_A/4$
C $g_B = 3g_A$
D $g_B = 2g_A$

18. Where would your weight be less than it is at sea level on the surface of the earth? (select all that apply)

A At the bottom of the ocean
B At the top of a mountain
C In an airplane flying at a constant velocity
D On the surface of a planet with four times the mass and twice the radius of earth

19. An object of mass m is held at a height of h above the surface of a planet of mass M and radius R. If the object is released and no other forces are acting on it (besides the gravitational force), what is its acceleration?

A $\dfrac{GM}{(R + h)^2}$

B $\dfrac{GMm}{R^2}$

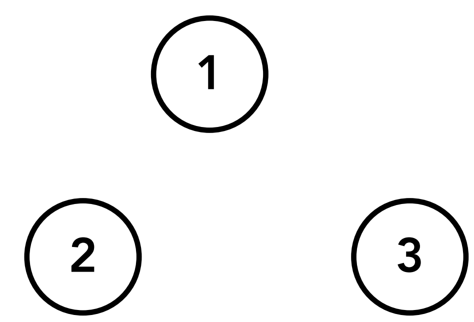
C $\dfrac{GM}{h^2}$

D $\dfrac{GMm}{h^2}$

20. On July 21, 1969 Neil Armstrong became the first person to step foot on the moon. What property(s) of Neil was different on the moon compared to when he was on earth?

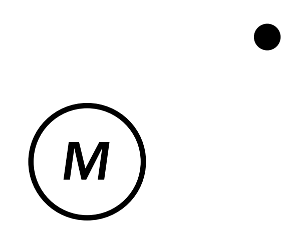
A His mass and weight
B His mass was different but his weight was the same
C His weight was different but his mass was the same
D None of the above, his mass and weight stayed the same

21. Three objects are shown on the right. Which of the following shows the direction of the gravitational force acting on object 1 from object 3?



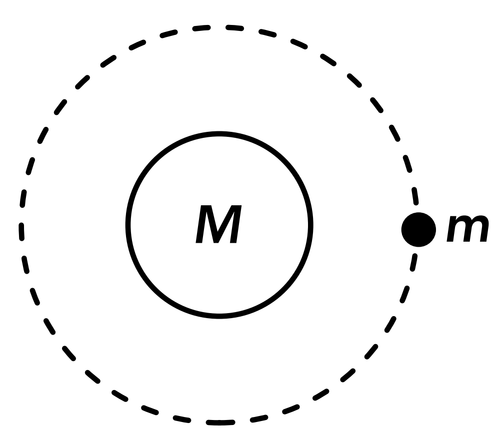
A B C D

22. Which of the following shows the direction of the gravitational field produced by mass M at location of the dot shown on the right?



A B C D

23. A small of mass m is orbiting a much larger mass M as shown on the right. Which of the following show the direction of the force acting on the larger mass from the smaller mass?



A B C D

24. What is the magnitude of the gravitational force acting on the earth from the sun? Use $\mathbf{6 \times 10^{24}\ kg}$ for the mass of the earth, $\mathbf{2 \times 10^{30}\ kg}$ for the mass of the sun, and $\mathbf{1.5 \times 10^{11}\ m}$ for the distance between the center of the earth and the center of the sun.

25. A new planet is discovered named "Planet X". Based on careful observation, astronomers are able to determine that Planet X has mass of $\mathbf{8 \times 10^{23}\ kg}$ and a radius of $\mathbf{2 \times 10^{6}\ m}$. If an astronaut traveled to Planet X and dropped a ball from rest from a height of 2 m, how long would it take to hit the ground (assuming the planet has no atmosphere and zero air resistance)?

26. How far above the surface of the earth would you have to be for your weight to be the same as it is on the surface of the moon? Use $\mathbf{6 \times 10^{24}\ kg}$ for the mass of the earth, $\mathbf{6.4 \times 10^{6}\ m}$ for the radius of the earth, $\mathbf{7.4 \times 10^{22}\ kg}$ for the mass of the moon and $\mathbf{1.7 \times 10^{6}\ m}$ for the radius of the moon.

Apparent Weight

27. In situations when you're standing and your apparent weight is equal to, less than or greater than your true weight, which force is responsible for the apparent weight that you feel?
   - A The weight force
   - B The gravitational force from the earth
   - C The normal force from the surface below you
   - D The apparent weight force

28. You're inside an elevator which is moving at a constant speed. How does your apparent weight compare to your true weight if the elevator is moving downwards? What if it's moving upwards?
   - A Your apparent weight is equal to your true weight / Your apparent weight is equal to your true weight
   - B Your apparent weight is less than your true weight / Your apparent weight is greater than your true weight
   - C Your apparent weight is greater than your true weight / Your apparent weight is less than your true weight
   - D Your apparent weight is less than your true weight / Your apparent weight is less than your true weight

29. A person with a mass of 70 kg is standing in an elevator. The cable suddenly breaks, allowing the elevator to fall at 9.8 m/s^2. After the cable breaks, what is the normal force between the person and the floor?
   - A 686 N
   - B 0 N
   - C 70 N
   - D 9.8 N

30. A person is riding on a rollercoaster when they go over the top of a hill. At that moment the normal force between the person and the seat below them decreases. What happens to the person's weight at that time?
   - A It increases
   - B It decreases
   - C It remains the same
   - D Cannot be determined

31. A 5 kg object is suspended from the ceiling of an elevator by a rope. The elevator is moving upwards at a constant speed. Over a period of 2 seconds the elevator comes to a stop. During those 2 seconds, the apparent weight of the object…
   - A is less than when the elevator was moving at a constant speed
   - B is greater than when the elevator was moving at a constant speed
   - C is the same as when the elevator was moving at a constant speed
   - D cannot be determined

32. Person A is in a high speed elevator moving downwards with a constant speed of 10 m/s. Person B is in an elevator moving downwards at 2 m/s and accelerating downwards at 1 m/s^2. If person A and person B have the same mass, which one is experiencing a smaller apparent weight?
   - A Person A
   - B Person B
   - C They have the same apparent weight
   - D Cannot be determined

33. In which of the following scenarios is the person experiencing weightlessness? (select all that apply)

A A person flying a small plane going through a short dive where the plane is in free fall

B A person standing in an elevator which is accelerating downwards at 3 m/s^2

C A person driving a car very fast over the top of a hill and momentarily loses contact with their seat

D A person standing on the ground who jumps into the air (during the period they're in the air)

34. A 65 kg person is standing on a scale in a moving elevator. While the elevator slows down, the scale reads 710 N. Was the elevator moving up or down?

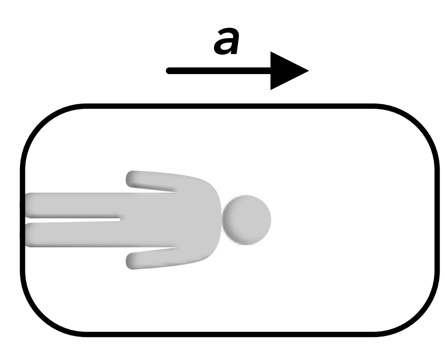
A Up

B Down

C The elevator was not moving

D Cannot be determined

35. An 85 kg astronaut is in a small spacecraft in outer space. Using thrusters, the spacecraft is able to simulate gravity for the astronaut inside who is "standing" with their feet in contact with the left wall as shown on the right. What should be the acceleration *a* so that the astronaut's apparent weight is the same as it is when standing on the surface of the earth? (Assume there are no gravitational forces acting on the astronaut).



36. An 80 kg person is in an elevator moving upwards at a constant speed of 3 m/s. The elevator then slows down with a constant acceleration and stops in 2 s. What is the person's apparent weight during the 2 s?

Answers

1. D	11. D	21. D	31. A
2. B, C	12. C	22. C	32. B
3. A, B, C, D	13. B	23. A	33. A, C, D
4. A, B, C	14. D	24. **3.6×10^{22} N**	34. B
5. C	15. A, B, C	25. 0.5 s	35. 9.8 m/s²
6. D	16. A, D	26. **8.9×10^{6} m**	36. 664 N
7. B	17. C	27. C	
8. A	18. B, C	28. A	
9. A	19. A	29. B	
10. B	20. C	30. C	

Answers - Gravitational Force, Gravitational Field and Weight

1. **Answer: D**
   According to Newton's law of universal gravitation, every object with mass attracts every other object with mass with a gravitational force. It doesn't matter how massive each object is.

2. **Answer: B, C**
   Remember that weight and mass are different, and weight is a force (a gravitational force) so the unit for weight is the Newton (N). A newton is derived from other SI units, $1\ N = 1\ kg \cdot m/s^2$.

3. **Answer: A, B, C, D**
   The gravitational force between two objects is always an attractive force and never a repulsive force. It doesn't matter how the masses of the two objects compare or where they are positioned relative to each other.

4. **Answer: A, B, C**
   From the equation for gravitational force (from Newton's law of universal gravitation) we can see that the force depends on the mass of each object and the distance between their centers (***r***) but it does not depend on the radius of either object. Each object is treated as a point mass, meaning all of its mass is concentrated at its center.

5. **Answer: C**
   The weight of the object is the gravitational force exerted by the earth on the object, which is equal in magnitude to the gravitational force exerted by the object on the earth (that is an equal and opposite force pair from Newton's 3rd law).

6. **Answer: D**
   In the equation for gravitational force, the magnitude of the force is inversely proportional to the square of the distance between the centers of the two objects. If the distance is multipled by 3 the force will be divided by 9.
   $$F_g = \frac{G m_1 m_2}{r^2}$$

7. **Answer: B**
   The force exerted on the block by the earth is a gravitational force, which is equal in magnitude to the force exerted on the earth by the block (this is a pair of equal and opposite forces from Newton's 3rd law).

8. **Answer: A**
   The gravitational force between two objects does not depend on the radius of either object so the gravitational force would not change.

9. **Answer: A**
The weight of an object is the gravitational force exerted on it by the earth (or other large body) which can be calculated using $F_g = mg$ where g is the acceleration due to gravity (or the strength of the gravitational field).

10. **Answer: B**
From the equation for gravitational force, the force is inversely proportional to the square of the distance the centers of each object. The smaller the distance between the planet and the sun, the greater the gravitational force between them.

11. **Answer: D**
The object and the building both have mass so they both exert a gravitational force on each other, so there is a force acting on the object caused by the building which points towards the building (that gravitational force). But if the object is at rest and not accelerating towards the building, the net force on the object in that direction must be zero, which means there must be another force or forces acting on the object which point away from the building. That could be a friction force or some other applied force (maybe the object is being held).

12. **Answer: C**
The gravitational force between the planets is given by the equation below:

$$F_g = \frac{Gm_1m_2}{r^2} = \frac{G(2m_1)(3m_2)}{(\sqrt{6}\,r_1)^2} = \frac{6Gm_1m_2}{6r_1^2} = F_g$$

13. **Answer: B**
The gravitational force exerted on object D by each of the other objects would be:

$$F_A = \frac{Gm_Dm_A}{r^2} = \frac{Gm_D(2\text{ kg})}{(3\text{ m})^2} = \frac{2}{9}Gm_D$$

$$F_B = \frac{Gm_Dm_B}{r^2} = \frac{Gm_D(10\text{ kg})}{(8\text{ m})^2} = \frac{10}{64}Gm_D$$

$$F_C = \frac{Gm_Dm_C}{r^2} = \frac{Gm_D(6\text{ kg})}{(4\text{ m})^2} = \frac{6}{16}Gm_D$$

14. **Answer: D**
A gravitational field exists around every object with mass, a second mass is not required to produce a field.

15. **Answer: A, B, C**
A gravitational field exists around every object with mass. If an object is in a gravitational field it will experience a gravitational force towards the object producing the field. The earth and the book both produce gravitational fields, and they each experience a gravitational force due to the other's field. We could also say that any two objects with mass attract each other with a gravitational force and exclude the concept of gravitational fields. In any case, the gravitational forces between the earth and the book are equal in magnitude.

16. **Answer: A, D**
The variable g represents the acceleration due to gravity and the strength of a gravitational field at any point in space (they're the same thing).

17. **Answer: C**
The strength of the gravitational field at a distance r from the center of an object with mass M is shown below. The radius of the object doesn't matter, only the mass and the distance from the center. The mass of object B is three times the mass of object A, so the strength of its gravitational field is also three times that of object A.

$$g = \frac{GM}{r^2}$$

18. **Answer: B, C**
Your weight depends on the strength of the gravitational field (or simply the gravitational force) which is proportional to the mass of the planet and inversely proportional to the square of your distance from the center of the planet. You're farther from the center of the earth when at the top of a mountain and in an airplane at any height above the ground. You would have the same weight on the surface of a planet with four times the mass and twice the radius of the earth.

$$F_g = \frac{GMm}{r^2}\text{, or } g = \frac{GM}{r^2} \text{ and } F_g = mg$$

19. **Answer: A**
The equation for the strength of a gravitational field at some point, which is also the acceleration due to gravity for any object at that point, is shown below. The variable r represents the distance from the center of the object producing the field (the planet), which in this case is the radius plus the height above the surface.

$$g = \frac{GM}{r^2} = \frac{GM}{(R + h)^2}$$

20. **Answer: C**
An object's mass is the same everywhere in the universe but an object's weight depends on g, the acceleration due to gravity or the strength of the gravitational field which is different at the surface of the moon than at the surface of the earth.

21. **Answer: D**
A gravitational force is always an attractive force. The gravitational force acting on object 1 from object 3 points from the center of object 1 to the center of object 3.

22. **Answer: C**
The direction of a gravitational field is always towards the center of the mass producing the field.

23. **Answer: A**
A gravitational force is always an attractive force, and the force acting on the larger mass due to the smaller mass points from the larger mass towards the center of the smaller mass.

24. **Answer: 3.6×10^{22} N**

$$F_g = \frac{Gm_1m_2}{r^2} = \frac{(6.67 \times 10^{-11})(6 \times 10^{24}\text{ kg})(2 \times 10^{30}\text{ kg})}{(1.5 \times 10^{11}\text{ m})^2} = 3.6 \times 10^{22}\text{ N}$$

25. **Answer: 0.5 s**
We can find the acceleration due to gravity at the surface of Planet X, then use kinematics to find the time.

$$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(8 \times 10^{23}\text{ kg})}{(2 \times 10^{6}\text{ m})^2} = 13.3\text{ m/s}^2$$

$$y_f = y_i + v_{yi}t + \frac{1}{2}a_y t^2 \qquad (0\text{ m}) = (2\text{ m}) + (0\text{ m/s})t + \frac{1}{2}(-13.3\text{ m/s}^2)t^2 \qquad t = 0.5\text{ s}$$

26. **Answer: 8.9×10^{6} m**
We can set the equation for the weight at a height above the earth and the equation for the weight at the surface of the moon equal to each other and solve for the height. Using h to represent the height above the surface of the earth:

$$F_{g\text{ earth}} = F_{g\text{ moon}} \qquad \frac{Gm_em}{(r_e + h)^2} = \frac{Gm_mm}{r_m^2} \qquad h = \sqrt{\frac{m_er_m^2}{m_m}} - r_e = 8.9 \times 10^{6}\text{ m}$$

Answers - Apparent Weight

27. **Answer: C**
    The normal force acting on you from below is the force that you experience as your weight. If that normal force increases or decreases (for example, if you were in an accelerating elevator) then your apparent weight will change, but your true weight (the gravitational force or weight force acting downwards on you) does not change.

28. **Answer: A**
    If the elevator is moving at a constant speed then you are not accelerating so the net vertical force acting on you is zero. That means your weight (the downwards gravitational force) is equal to your apparent weight (the upwards normal force from the floor) in both cases. Your apparent weight would change if the elevator was accelerating in either direction.

29. **Answer: B**
    The elevator and the person are both in free fall. There is the gravitational force acting downwards on the person but there is zero normal force acting upwards on the person. The net force is just the gravitational force, causing them the accelerating downwards at 9.8 m/s².

30. **Answer: C**
    During the period when the normal force decreases the person's apparent weight decreases but their weight remains the same (weight is the gravitational force acting downwards on the person from the earth).

31. **Answer: A**
    The apparent weight of the object is the tension force in the rope. During the 2 seconds that the elevator changes from moving upwards at a constant speed to having no speed, the elevator is accelerating downwards. There is a downwards gravitational force (weight force) acting on the object and an upwards tension force. Since the acceleration is downwards the net force on the object is also downwards, so the tension force is less than the weight force and the apparent weight is less than the true weight.

32. **Answer: B**
    Person A is moving at a constant velocity and zero acceleration, so their apparent weight is equal to their true weight (the upwards normal force is equal to the downwards gravitational force) regardless of the velocity. Person B is accelerating downwards so the net force acting on them is downwards and their apparent weight (the upwards normal force) is less than their true weight (the downwards gravitational force).

33. **Answer: A, C, D**
    A person (or object) experiences weightlessness when their apparent weight is zero. This happens when there is no normal force or contact force supporting them from below so they are in free fall, accelerating downwards at 9.8 m/s². The person in the elevator accelerating downwards at 3 m/s² still experiences an upwards normal force.

34. **Answer: B**
    The true weight of the person is 637 N ($F_g = mg$). 710 N is the person's apparent weight while the elevator slows down. Since their apparent weight is greater than their true weight, the normal force acting upwards on them must be greater than the gravitational force acting downwards. The net force must be upwards so the acceleration is upwards. If the elevator has an upwards acceleration and is slowing down, its velocity must be downwards.

35. **Answer: 9.8 m/s²**

The astronaut's apparent weight will be the same as it is on the surface of earth if the acceleration is the same as the acceleration due to gravity $\boldsymbol{g}$, 9.8 m/s². Their apparent weight is the normal force acting them by the surface they're standing on. When on earth, that formal force is equal to their true weight force which is $F_g = mg$. In the spacecraft, the normal force from the wall must equal their weight force on earth, which will result in the person accelerating at 9.8 m/s².

36. **Answer: 664 N**

The person's apparent weight is the normal force acting on them during the acceleration period, which can be found by drawing a free body diagram and applying Newton's 2nd law.

$$a_y = \frac{\Delta v_y}{\Delta t} = \frac{(0\text{ m/s}) - (3\text{ m/s})}{2\text{ s}} = -1.5\text{ m/s}^2$$

$$\sum F_y = ma_y \qquad F_n - F_g = ma_y \qquad F_n - (80\text{ kg})g = (80\text{ kg})(-1.5\text{ m/s}^2) \qquad F_n = 664\text{ N}$$