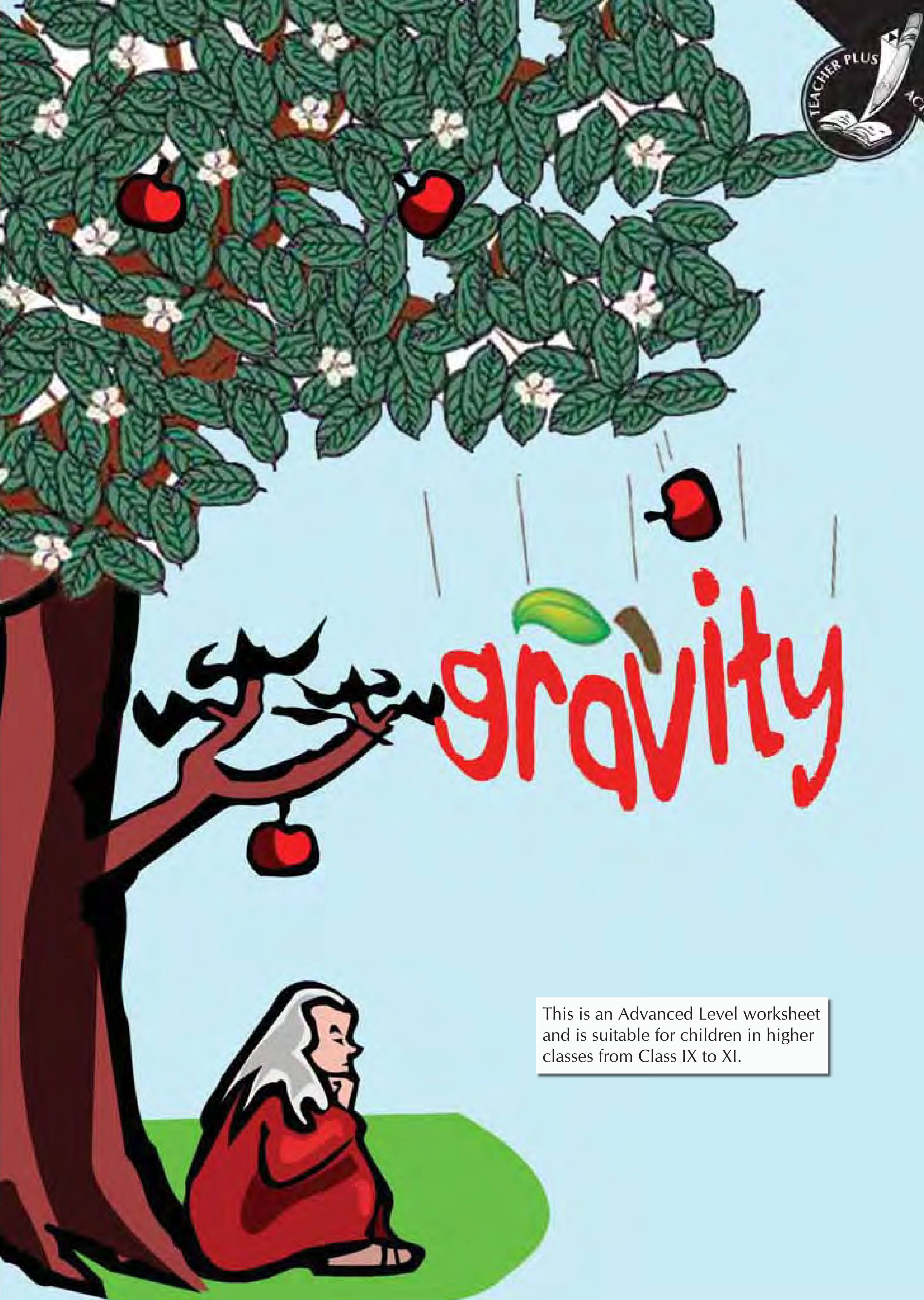

This is an Advanced Level worksheet and is suitable for children in higher classes from Class IX to XI.

Teacher Plus Worksheet

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Gravity

We are born into a world controlled and structured by gravity. That is why we take its presence for granted. But if we give it a second thought, we will realize that because of gravity, we know what is up and what is down. In fact, what goes up comes down because there is gravity. We can distinguish between high and low because of gravity, we can hold our ground, we can drink water, toss coins and we get rain. Gravity prevents our lives from being topsy turvy.

Natural philosophers through the ages have thought about gravity, but Aristotle was way off the mark when he said that it is the natural tendency of some substances like smoke and fire to go up and some other substances like stones to come down. True understanding of gravity and its life shaping role in our lives came with the dawn of the Scientific Revolution. Scientists like Copernicus, Galileo and Keppler worked on the dynamics of heavenly and earthly bodies without pinpointing the role played by gravity in determining the trajectories of these bodies. It was left to Newton to bring in the idea of action at a distance – that two objects can exert a force on each other without coming into physical contact. He called this force the force of gravity.

In this worksheet, we shall take a closer look at gravity and understand how gravity shapes our lives and what life can be in the absence of gravity. Let us do a warming up exercise by answering the following questions:

1. Think of one activity in your everyday life that is not affected by gravity: ______________

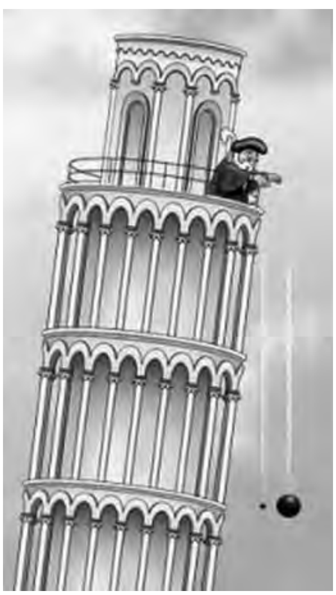
2. Think of one activity where gravity is a big help: ________________________________

3. Think of one activity where gravity is a hindrance: _______________________________

The only instance where the effect of gravity is not registered is when we succumb to gravity completely without putting up a resistance. It is called the state of free fall.

Free fall

When an object moves only under the force of gravity (and no other force acts on it), the object is said to be falling freely. It does not matter in which direction the object is actually moving.
When we play with a ball and throw it high up in the sky, it enjoys a state of free fall for as long as it is going up and coming down. But for how long? Does it depend on the size of the object? Does it depend on its shape? Galileo was fascinated with falling objects. He went up the top of the Leaning Tower of Pisa and threw down balls of various sizes. He discovered that all the balls take the same time to reach the ground. That was a big revelation – the time of free fall does not depend on shape, size or weight.



4. If we presume that the Leaning Tower of Pisa is 50 metres high, how long did Galileo's balls take to hit the ground?

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5. Do we have to go all the way to Pisa to verify Galileo's experiment or can we verify it here and now? Think of a way in which you can verify Galileo's experiment right at your study table. Take a heavy book and a paper which is slightly smaller than the size of the book. Hold them with your two hands and release them at the same time. Of course, you have to throw them from the same height. Watch how they fall. Think of a way by which you can make them fall at the same rate.

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6. Now imagine the situation described below and answer the questions that follow:

   Sachin Tendulkar hits a ball with all his might. The ball flies off at an angle of 45 degrees with an initial velocity of 100 Km / hr and lands right outside the stadium.

   i) For how long did it remain in a state of free fall?

   ii) How high did the ball rise?

   iii) What approximations have you made in your above calculation?

   iv) What is the horizontal distance covered by the ball?

7. Can you think of a situation where an object is in a state of perpetual free fall? Imagine the situation described below and answer the questions that follow:

   Drill a hole right through the centre of the earth and release a ball into this hole. It is easy to guess that the ball will freely fall towards the centre of the earth.

   a) But will the acceleration of the ball remain constant?

   b) Can you write an equation to show how the acceleration of the ball will change with time? (Hint: When an object is inside a shell, the shell does not exert any gravitational force on the object).

   c) According to this equation, at what points will the ball experience maximum acceleration?

   d) Will there be any point where the ball will have zero acceleration?

   e) If at all there is a point where acceleration is zero, will the ball come to a stop at this point?

   f) Can you graphically represent how gravitational force on the ball will change with distance from the centre of the earth? Represent the position of the ball from the centre of the earth along the X axis and the acceleration of the ball along the Y axis.

   g) Can you graphically represent the path of this ball? Represent time on the X axis and distance from the centre of the earth on the Y axis. At time ‘0’, the ball is at R, where R is the radius of the earth. Now mark subsequent positions of the ball at regular intervals of time.

   h) When and where will the journey of the ball end?

Weightlessness

We tend to use the terms 'weight' and 'mass' interchangeably. But mass is an intrinsic property of an object, whereas its weight depends on the situation it is in.

Weight is defined as the measure of the force of gravity experienced by an object. But weight is measured only when there is a resistance to this force of gravity. For example, when you hang a mass to a spring balance, the spring balance pulls up the mass and prevents it from falling. This force exerted by the spring is registered as the weight of the mass. It is exactly equal and opposite to the earth's pull of gravity on the mass. Similarly, if we stand on a weighing balance, the force with which the balance holds us up and prevents us from falling, is registered as our weight. But if we fall freely along with the balance, the needle of the balance will not move and our weight will be registered as zero. So if we are standing on such a balance in an elevator and, God forbid, if the cord of the elevator snaps, we shall become weightless. **Objects become weightless in a state of free fall**. But that does not mean that they lose their mass or that the earth stops pulling them.

8. i) Can you think of a way of measuring the mass of an object when it is in a state of free fall? You may assume that you are inside a space-lab orbiting the earth and consider using a spring with a known spring constant.

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   In the solar system, you will find many objects in a state of free fall. All the planets are falling freely towards the Sun, the moon is falling freely towards the earth, Europa and Io are falling freely towards Jupiter and even Halley's Comet is falling freely towards the Sun.

   ii) We have been arguing so far that a state of free fall is a state of weightlessness. If the earth is falling freely towards the Sun and we are a part of the earth, why do we earthlings have weight?

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   iii) According to Newton's third law of motion, to every action there is an equal and opposite reaction. If the Sun is pulling the Earth, the Earth is also pulling the Sun with an equal and opposite force. Then why does the Earth fall towards the Sun and not vice versa? Similarly, after we kick the football, does the football hit the ground or the ground hit the football?

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   iv) The trajectories of all heavenly bodies are determined by two factors – one – the gravitational force experienced by them towards the Sun or the planet around which they are orbiting and their initial velocities – that means, the velocities they acquired at the time of creation. Usually these orbits are elliptical instead of circular. Of all the heavenly bodies mentioned above, Halley's Comet has the most elliptical orbit and Mercury has the least elliptical orbit.

   v) Supposing the positions of Earth and Jupiter were interchanged in our solar system. How will their respective orbits duration of a year change?

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9. You might have seen in the movies sky divers taking a plunge from airplanes. There was a particularly memorable sky diving sequence in the movie *Zindagi na milegi dobara*. Are these sky divers in a state of free fall? Imagine yourself to be a sky diver and answer the following questions, given the fact that the air offers resistance (that is, an upward force) proportional to the velocity of the falling body:

a) What is the velocity of the sky divers when they begin their fall to earth?

b) What is the acceleration of the sky divers at the start of their fall?

c) Besides the force of gravity, what other force can possibly be acting on the sky divers?

d) How do the velocity and acceleration of the divers change as they descend towards the earth?

e) Are the falling sky divers in a state of weightlessness?

f) Supposing a falling sky diver measures the weight of a small iron ball using a spring balance. Will the spring balance register the true weight of the ball?

g) When do the divers know that they have to release the parachute? What additional force comes into play when the parachute is released?

h) Do the divers fall straight or can they steer their path during their fall?

i) Watch the sky diving video with the following link:
http://www.youtube.com/watch?v=I2ciOr6l1ss&feature=player_detailpage
In this video, the fall of the two sky divers has been captured by another sky diver whose hands and feet we occasionally glimpse. The video ends with the two sky divers opening the big parachute and moving up – high up in the sky. Explain the motion of the sky divers as captured by the camera. Do the sky divers really move up or do they just seem to move up?

j) Can you imagine the flight of the sky divers after the video ends? Will the two divers move up into space or will they ever come down to earth?

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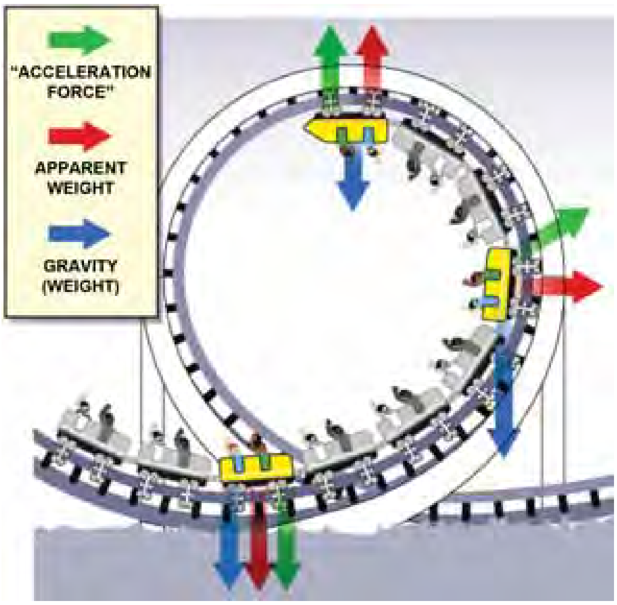
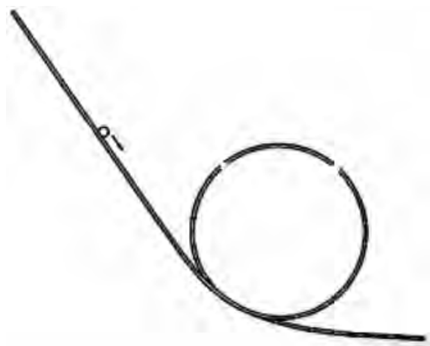
Defying gravity



Sky divers surrender to gravity till the parachute unfurls. But defying gravity has its own thrills. You might have experienced some gravity defying rides in entertainment parks.

You can do the following experiment at home:

10. Take a curtain rail or a rubber pipe and bend it in the following shape. Make sure that the straight portion on the left hand side is quite long. Now keep dropping small round pellets from different heights of the left hand incline and see which one succeeds to loop the loop.



i) Calculate the minimum height required to loop the loop.

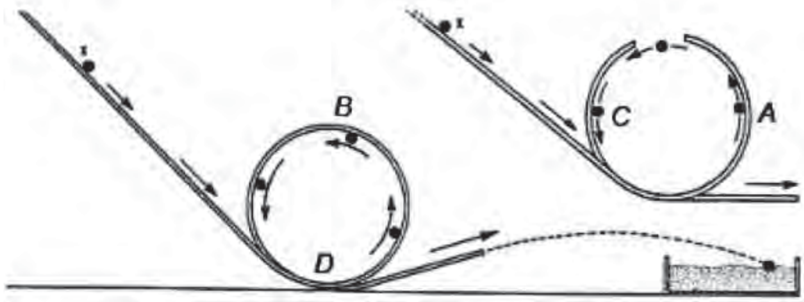
ii) What approximations have you done in doing this calculation?

iii) Draw the forces on the pellet when it is at the highest point of its trajectory and when it is at the lowest point.

iv) Is there any point where the pellet becomes weightless?

v) Supposing you keep another exactly identical pellet at the bottom of the loop. What will happen when the pellet that you drop comes and hits this pellet?

vi) Supposing the curtain rail is broken and there is a small gap at the top as shown below. Will the pellet fall off at this point?



vii) How will all your above observations change if instead of a tiny pellet you take a bigger sphere?

11. Before ending, let us enjoy the gravity defying rides and ponder upon the questions that follow:

How do circus motorcyclists perform these gravity defying feats? What keeps them from falling down the slide? (Hint: The walls of the 'death wells' are built at a slight incline. They are not completely vertical).

Answers and hints

1. Any non-mechanical activity like reading a book, taking print outs from a printer etc.
2. Water flows to our taps from the overhead tank because of gravity, we can gulp down water because of gravity, ink flows from the pen because of gravity, our walking is assisted by gravity, a pendulum clock works because of gravity.
3. We cannot lie down on our back and write, we fall down and hurt ourselves because of gravity, stacked books and other things fall down as soon as centre of gravity moves outside the base of support.
4. Calculate by the formula $H = \frac{1}{2} gt^2$ ($h = 50m$, $g = 9.8m/sec^2$).
5. Keep the page on the book and drop the book. The book and the page will land together. This is because the heavy book removes the air from its path and the paper does not experience any air resistance or buoyant force to keep it afloat. The situation is similar to the paper falling in vacuum.
6. i) The vertical velocity of the ball is $V\sin\theta$, where $V = 100Km/hr$ or $1/36$ Km/sec and $\theta = 45$ degrees. It keeps rising till its vertical velocity becomes zero. Apply the formula $v = u + gt$. V is the final velocity $= 0$. U is the initial velocity $= V\sin\theta$. $g = 9.8m/sec^2$. 't' is the time of rise. The time for which it stays in air is 2t. This is also the time for its free fall.
   ii) Once you have the time 't', how high it rises can be calculated by the formula $H = ut + \frac{1}{2}gt^2$.
   iii) Factors not taken into consideration are air friction and spin of the ball.
   iv) Horizontal distance covered is $V\cos\theta$ X 2t.
7. a) No. Acceleration will be the highest at the surface of the earth and zero at the centre.
   b) As the ball moves towards the centre of the earth, the outer shell of the earth ceases to exert a gravitational pull and only the inner core exerts a pull. If the force of gravity on the ball is $GM_e m_b/R^2$, the acceleration due to gravity is GM_e/R^2. But M_e, that is the mass of the earth exerting a pull on the ball is variable. M_e = Density (D) of the earth X (4/3) πR^3.
   Therefore, acceleration due to gravity $g = (4/3)\ \pi GDR$. Acceleration of the ball is directly proportional to its distance from the centre of the earth.
   c) Maximum acceleration will be at the surface of the earth.
   d) Zero acceleration will be at the centre of the earth.
   e) The ball will not stop at the centre of the earth and continue its motion towards the surface because of its momentum.
   f) Acceleration Vs. distance graph will be a straight line passing through the centre.
   g) The ball will execute a simple harmonic motion. So the graph of its journey will be sinusoidal (sine curve).
   h) Ideally, the journey of the ball will never end. It will perpetually swing back and forth from one end of the earth to the other.
8. i) Take a spring with a known spring constant k. Fix one end of the spring to a rigid wall and fix the mass to the other end of the spring. Then stretch the spring and leave it. It will continue to oscillate. The time period of oscillation will depend on the spring constant and the mass. $T = 2\prod(m/k)^{\frac{1}{2}}$. Thus, if we measure the time period of oscillation, we can calculate the mass.
   ii) Our weight is determined by the pull of gravity towards the centre of the earth. So we are perhaps weightless with respect to the Sun, but not with respect to the earth.
   iii) Strictly speaking, the Sun and the Earth are falling towards each other and they are going round around a common centre of mass. But the Sun is so much heavier than the earth that the common centre of mass lies inside the surface of the Sun and its acceleration is barely noticeable. By a similar argument, the earth's acceleration towards the football is negligible.
   iv) If the positions of Earth and Jupiter were interchanged, then Earth would continue to move in Jupiter's orbit and vice versa. This means that the time period of Jupiter's orbit will become one earth year and the time period of earth's orbit will become one Jupiter year. According to Kepler's law, T^2 is proportional to R^3. The time period is independent of the mass of the planet.
9. a) Initial velocity of the sky divers is equal to the velocity of the aeroplane from which they are falling.
   b) Initial acceleration of the sky divers is equal to 'g'.
   c) Besides gravity, the other forces on the sky divers are buoyant force and viscous force of the air.
   d) Due to acceleration due to gravity, the velocity will keep increasing, but as the velocity increases, the viscous drag also increases. At one stage, the viscous drag will be equal and opposite the force of gravity. The divers will then stop accelerating and fall with a terminal velocity.
   e) When the sky divers attain a terminal velocity, they are no longer in a state of free fall. Thus they are not weightless.
   f) The spring balance held by the sky diver will not register the true weight of the ball. The weight registered will be the force of gravity minus the air resistance.
   g) When the parachute is opened, the air resistance increases several times. The air rushing against the sky diver hits against the parachute umbrella and exerts a braking force. The diver attains a new state of equilibrium with a much lower terminal velocity.
   h) Divers can steer their path by changing the orientation of the umbrella of the parachute.
10. i) In order to loop the loop successfully, at the top of the loop, the centripetal force should be equal to the force of gravity. $Mv^2/R = Mg$; By law of conservation of energy, $MgH = Mg2R + Mv^2/2$. Solving these two equations we get $H = 5R/2$
    ii) We have ignored the rotational energy of the ball
    iv) The pellet becomes weightless at the highest point of the loop.
    v) If we keep another exactly identical pellet at the bottom of the loop, the first pellet will stop dead on collision and the second one will take off with all the momentum of the first pellet.
    vi) The pellet will not drop off at the gap because of its forward momentum. If it is small enough to pass through the gap, it will dash off tangential to the loop.
    vii) A bigger sphere will roll down and it will have considerable rotational energy. So it will have to be dropped from a higher level.
11. The force of gravity downwards is balanced by the frictional force upwards while the normal reaction from the wall provides the centripetal force needed for circular motion.

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