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What does dynamics mean?

■ We encounter dynamics everywhere in our daily life and perhaps no longer even recognize it because we are so used to it! We speak of dynamics everywhere anything moves.

We experience this in the morning when we get up. We move from our bed to the bathroom or the breakfast table. We drive or walk to school or to work. We experience the effects of dynamics in nearly all hobby sports or see them when we simply watch other people move.

Fun with Physics

Dynamics provides us with awesome experiences and fun, such as riding your bike, skiing, skateboarding, playing ball or riding a roller coaster. Dynamics therefore enriches our lives, as expressed in the motto – Fun with Physics!

Try to think where you encounter dynamics in your everyday life!

- Riding in a car
- running, jogging, jumping
- ...

Did you know that dynamics is even a branch of physics dealing with all processes involving motion? Some of these various physical effects are shown and explained in various experiments in this activity booklet.

Relationship between force and dynamics

Model for experiment 1

Why do things move

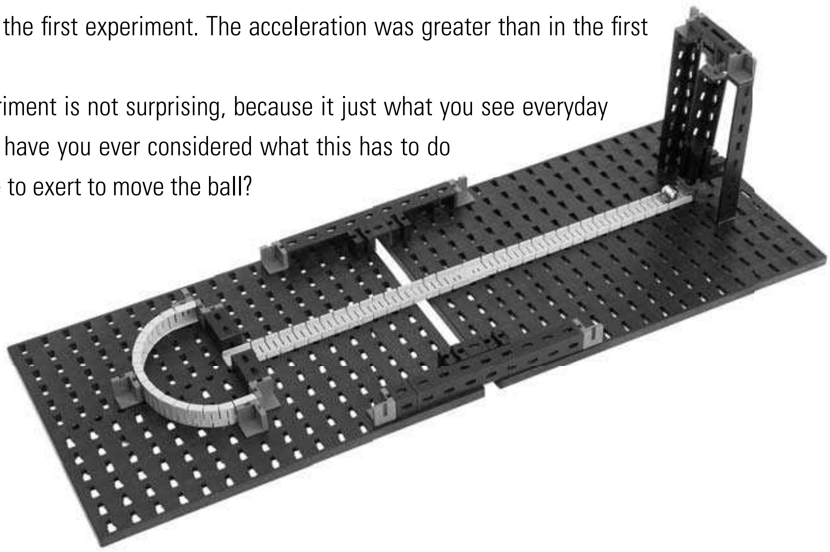
■ To understand dynamics it is important to know what causes them. The next two simple experiments explain why something moves. In the introduction we already established that whenever anything moves, dynamics are involved.
Set up the model for experiment 1 (level track) to perform these experiments.

Task:
Place a ball in the track and give the ball a very gentle push (with very little force). What happens? How much is the ball accelerated by this little push?

It moves slowly – it may even stop rolling. The acceleration was minimal.

Task:
Now place another ball in the track and push it a little harder than in the first experiment (with more force than in the first experiment). What happens? How much is the ball accelerated by pushing it harder?

It moves faster than in the first experiment. The acceleration was greater than in the first experiment.
The result of this experiment is not surprising, because it just what you see everyday with every motion. But have you ever considered what this has to do with the force you have to exert to move the ball?



Physical explanation

The relationship consists of a mass (weight of the ball) and an accelerating force (the ball is accelerated from a resting position) and this required that you exert a force (muscle power). This relationship can be described in an equation which is used as the "Definition of Force".

$$Force = Mass \times Acceleration$$

or using the appropriate physical abbreviations

$$F = m \times a$$

Physicist Sir Isaac Newton (1643–1727)

■ In the second experiment you exerted a greater force than in the first experiment, however the mass of the ball remained the same. For this reason the acceleration was greater in the second experiment than in the first experiment.
Force is measured in Newtons [N]. This unit of measure was named after the physicist Sir Isaac Newton, who first formulated the basic laws of motion.

More or less force?

Now you can consider whether more or less force is required in the following everyday examples:

Task:
You ride off on your bike alone. Along the way you meet a friend, who wants to hitch a ride. He sits on the back of your bike and you continue on together. If you accelerate as quickly as you did previously, will you require more or less force?

You need more force, if you want to accelerate as quickly as before, because the mass is greater.

Which ball flies farther?

Task:
You accelerate two balls with different weights, for example, a tennis ball and a shot put ball. If you attempt to throw both with all your strength, which one will accelerate faster, or, in other words, which one will fly the farthest?

If you use all your strength, the tennis ball will accelerate faster, because it is lighter than the shot. For this same reason it will also fly farther than the shot.

The following exercise is a little more more complicated, but can also be solved. Your new knowledge is the key:

Which one is heavier?

Task:
On a 100 m track: Runner 1 and runner 2 are equally strong, i.e. have the same muscular strength. Runner 1 accelerates faster. Which runner is heavier according to the theory?
Tip: Use your new knowledge (Force = Mass x Acceleration). Think of how the equation applies to each of the two runners.

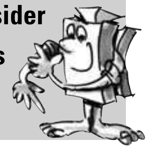
According to the theory, runner 2 should be heavier. Since he isn't stronger, he accelerates more slowly.

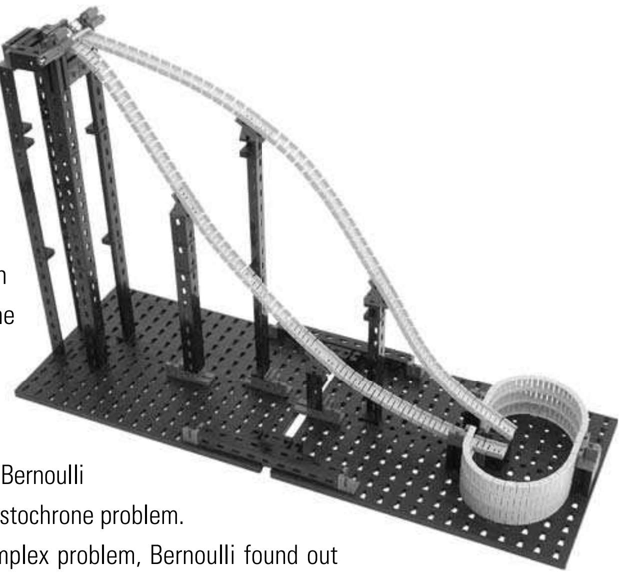
Which track is faster?

■ Since we know that forces are involved with all motions, the next experiment attempts to determine whether the path has any influence on the motion.

Set up the model for experiment 2 (acceleration) with the two different track shapes. One track is arched upward and the other downward. When you are through, start the experiment.

Task:
Place a ball at the top of each track. Before releasing the ball consider which track is faster! Now you can release the balls simultaneously. Moreover you can consider why the balls roll to the bottom at all. Here is a tip – the reason is the same as why things fall to the floor.





And – did you bet on the right track?
On the track arched downward the ball is faster than on the track with the upward arch.
Why? Is one track perhaps longer than the other? No – you installed three sections in each. Perhaps it has something to do with the shape of the track? Let's check with the mathematical encyclopedia.

Considered mathematically...

■ The problem of the fastest track was solved in 1696 by the mathematician Johann Bernoulli and is known in mathematics as the Brachistochrone problem.
When he attempted to solve this very complex problem, Bernoulli found out that the fastest of all curves is a track which arches downward, a so-called cycloid or rolling curve. This curve is even faster than a straight line, although this would represent the shortest connection between two points. The rolling curve is called a cycloid, because this curve can be generated by rolling a cylinder along a plane.

Why do the balls move down at all?

■ When you considered why the ball rolled down at all, you may have noticed that you did not exert any force to start the ball moving. If you now think back to our first experiment, you certainly remember that motion is not possible without the effect of a force. Since the ball moves, a force must also be acting here. The force pulling the ball down is the so-called force of gravity. It acts on all things on earth.

Gravity in everyday life ...

The force of gravity is all around us everyday. It is the force that causes everything to fall perpendicularly to the ground. Think of a few examples of this in your everyday life.

- Bungee jumping
- high diving, cliff jumping, parachute jumping
- Apple falls from tree
- ...

... and on the moon?

Did you know that there is also a force of gravity on the moon, that the moon itself exerts? Have you ever seen videos of astronauts on the moon? The astronauts can jump considerably higher and further than on the earth. Because the moon is much smaller than the earth, the gravitational force there is significantly lower than on the earth. This means that when you jump on the moon, you go a good deal further than on the earth.

Looping

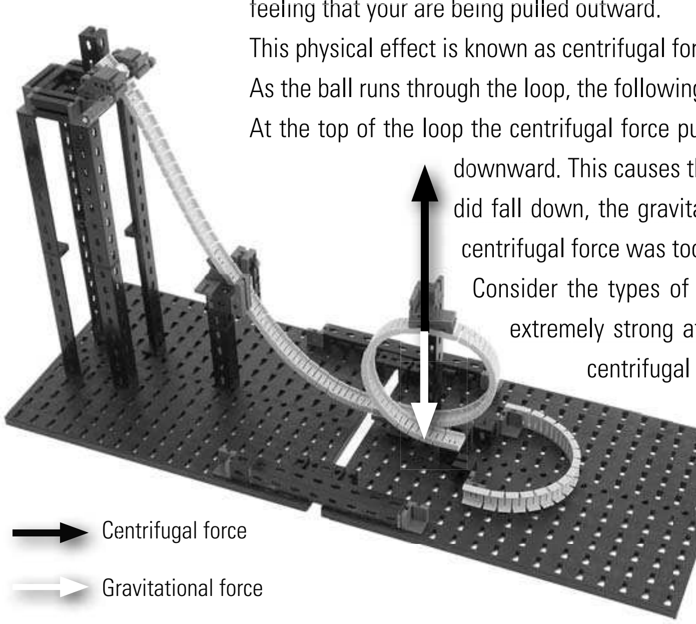
■ Since we now also know that there is a gravitational force, we can now proceed to the next experiment. Perhaps you have been in an amusement park or at a county fair with rides and roller coasters. If so, you are certain to have seen the impressive loops the roller coaster runs through. Build the model for experiment 3 (looping) to perform the next experiment.

Task:
After you have finished building the looping model, you can start the experiment. Experiment to find out how high you need to start the balls so that they will run all the way through the loop. Consider why the ball does not fall straight down at the top-most point, even though you just learned that the force of gravity pulls everything to the ground.

What happens in a loop?

If you have ever ridden in a roller coaster, you know that you were pressed into your seat in the loop. The same happens, for example, when you hold hands with someone else and turn in a circle. You have the feeling that your are being pulled outward.
This physical effect is known as centrifugal force.
As the ball runs through the loop, the following happens:
At the top of the loop the centrifugal force pushing upward is greater than the force of gravity pulling downward. This causes the ball to remain in the track and not fall down. If the ball did fall down, the gravitational force was greater than the centrifugal force. The centrifugal force was too low, because the ball accelerated too slowly.
Consider the types of sport where centrifugal force plays a role. Tip: Usually extremely strong athletes, such as those at the Olympic Games, make use centrifugal force by whirling in a circle.

- Hammer throwers
- Discus throwers
- Shot putters



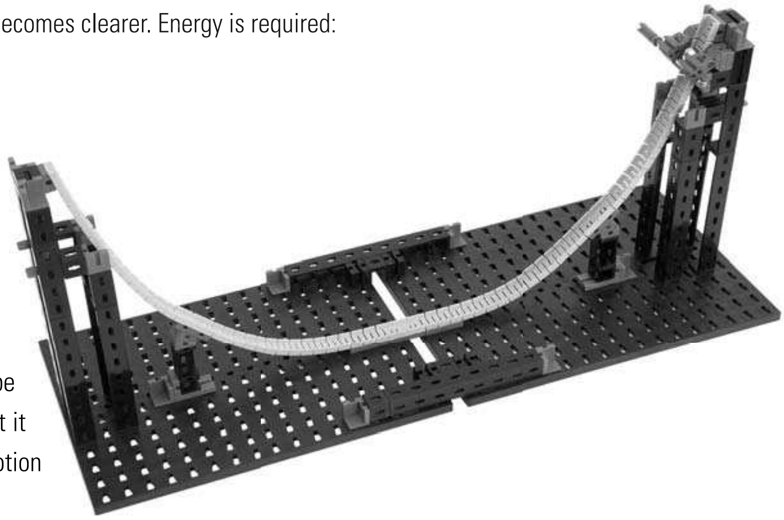
Centrifugal force

Gravitational force

What is energy?

■ Since we have already heard a great deal about various forces and motions, let's proceed to the next experiments. These are intended to illuminate the subject of energy in a little more detail. Certainly you will now ask what do forces, motions and energy have to do with one another.
When we investigate, what we need energy for, this question becomes clearer. Energy is required:

- to exert a force
- to accelerate or lift a body
- to heat or warm up something
- to get an electric current to flow and
- simply to live – examples are all humans, animals and plants



■ Energy is available in highly varying forms and these can be converted to other forms of energy. In the following experiment it is necessary to understand the difference between energy of motion and energy of rest.

Various forms of energy

Energy of motion is also called kinetic energy. Kinetic energy is present whenever an object moves. An example of this is a rolling ball in your Profi Dynamic Construction Set, because it moves and therefore has energy of motion.
The energy of rest, also known as potential energy, increases the higher an object is located. This means, for example, that a ball lying on a table, has more potential energy than one on the floor.

■ Enough theory, let us try this out on a model. For this purpose build the model for experiment 4 (half pipe).

Task:

Release a ball at the top of the half pipe and observe what happens. Consider which forms of energy you can see and where these are greatest.

The science of physics says:

"You can't make something out of nothing"

To understand the half pipe, it is necessary to know the so-called law of conservation of energy.
The law of conservation of energy says that the sum of all energy always remains the same. Energy cannot be created from nothing, nor can it be lost. Energy can only be converted from one form to another.

Half pipe

In the experiment in the half pipe, two forms of energy occur.

- Kinetic energy
- Potential energy

The energy you put into this experiment, is from your muscles lifting the ball upward. This give the ball more potential energy. As stipulated by the law of conservation of energy, this potential energy can be converted to kinetic energy, as soon as you release the ball.
The potential energy of the ball is greatest when the ball is released into the half pipe and it is lowest at the bottom.
The kinetic energy behaves in precisely the opposite manner as the potential energy. It is zero just before the ball is released, because nothing is moving. It is greatest at the bottom, because here the ball moves fastest.

Energy is measured in Joules [J]. This was named after the British Physicist James Prescott Joule.

Energy in your everyday life

■ Energy confronts us continuously in our everyday life, in the same manner as forces. For example, have you ever noticed the text on processed foods? Every box of corn flakes, candy, etc. – actually nearly all packaged foods – have such notices.
They frequently indicate the "Calories" contained. This is the amount of energy contained in the food. The term calories is used because the energy is "burned" in your body, in order to use it to run, jump and think.
The calories are usually listed in Kilojoules [KJ], corresponding to 1000 Joules [J] and in kilocalories [kcal] corresponding to 1000 calories [cal]. You may have already run into the word kilocalories in context with foods – it is another unit of measure for energy similar to the Joule.
It is very easy to convert one to the other using the following formula:

$$1\ Kilojoules \approx 4.18\ Kilocalories$$

or using the appropriate physical abbreviations

$$1\ kJ \approx 4.18\ kcal$$

James Prescott Joule (1818–1889)

Why does the ball stop?

■ Since we learned in the previous experiment that, according to the law of conservation of energy, energy can only be converted and not lost, the question arises, why the ball stops? If energy cannot be lost, shouldn't the ball continue to roll?

Task:
Perform the previous experiment with model 4 (half pipe) again. This time consider why the ball stops at some point. Tip: Run your finger along the track.

You can feel a resistance and also notice that the surface of the track is not perfectly smooth. This effect is known as friction. You may have heard the word friction before, but what is friction exactly and where does it come from?
Friction is an effect occurring between two objects (so-called external friction), when the surfaces touch one another. To understand why the ball stops, it is necessary to look at the surfaces of the ball and the flex rails under high magnification.

Surfaces magnified highly

Physics of friction

■ If you now image the surfaces 'hooking' on to one another, it is clear that the ball slows down after a time, because it has to continuously overcome these irregularities. Physically the energy here is converted to heat (thermal energy) by the effect of friction. When the ball stops rolling, all of the potential/kinetic energy has been converted to heat by the effect of friction. The resulting heat is so-called 'waste energy', because it can no longer be used and is 'wasted' so to speak.

The friction also be subdivided into adhesion or static friction, sliding friction and rolling friction.

- Static friction: The friction is so great that the two surfaces adhere to one another and do not move.
- Sliding friction: The friction is just high enough to allow the two surfaces to slide on one another.
- Rolling friction: This type of friction occurs when an object rolls on a surface.

Friction in your everyday life

You can test one example of heat produced by friction by rubbing your hands together. You will notice after a short time that they become warmer very quickly.

Since you now know the three different types of friction, you can assign the right type of friction to the examples here:

	Static friction	Sliding friction	Rolling friction
Riding a bike			×
Bead of glue on paper			
Skiing			
Ice skating			
Velcro fastener			
Ball in a track on your Profi Dynamic Construction Set			
Inline skating			

Balls hit together

■ You can build the model for experiment 4 (half pipe) for the following experiments,.

Task:
Place two balls at the bottom of the half pipe and let another ball roll down from the top. What happens?

The last ball is pushed away. The impact seemed to go right through all the balls.

Task:
You can position additional balls in the half pipe. What happens then ?

The same as in the first experiment. The last ball is pushed away. The impact seemed to go right through all the balls.

Task:
Now see what happens when you place three balls at the bottom and release two balls into the half pipe simultaneously from one side.

Now the last two balls are pushed away. The impact again goes right through all the balls.

■ The physical effect demonstrated here so-called elastic collision. An elastic collision is a contact between two objects lasting only a few milliseconds. During this period one ball transfers it kinetic energy to another, without deforming the balls. If a number of balls are placed next to one another, the impact passes through all of them. Exactly the same number of balls colliding are pushed off at the other end. The effect passing through the balls is called an impulse. Actually every mass, moving at a velocity, has an impulse. This means, as soon as you move, you have an impulse.

$$Impulse = Mass \times Velocity$$

$$p = m \times v$$

Impulse remains impulse

However the impulse is not always visible when a collision occurs, because only then is the impulse transferred. Similar to the law of conservation of energy, which says that 'the total amount of energy always remains the same', there is also a law of conservation of impulse. This law says that the impulse always remains the same even in the event of a collision.

$$Impulse_{\text{before collision}} = Impulse_{\text{after collision}}$$

We also saw this in our experiment, because the velocity and mass of the colliding balls was exactly the same as the velocity and mass of the balls pushed off.

Impulses in everyday life

■ There are many everyday examples of collisions. A good example of a collision is a carpenter hammering. Collisions are also easy to recognize in various types of sports such as billiards, squash, or curling. These examples use the effect that the impulse before the collision is the same as the impulse following the collision.

In billiards this effect is used to knock your own balls into a pocket following a collision with the white ball. These collisions are elastic exactly as in your experiments, because the state of motion of the balls is changed by the collision without deforming them.

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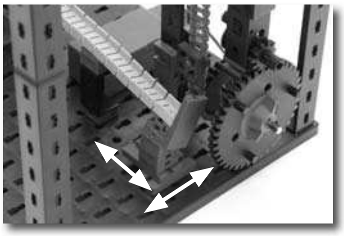
Large obstacle courses

■ You can use the physical effects you learned in the previous experiments to construct fascinating obstacle courses for steel balls with various obstacles and surprising effects.

Elevator

All obstacle courses shown in the assembly instructions include an elevator. This consists of a driven chain fastened to a magnetic ball holder.

As soon as a ball holder passes by a steel ball in the model's magazine, it is attracted by the magnet and transported to the top. At the top the ball is pushed off and rolls through the obstacle course.

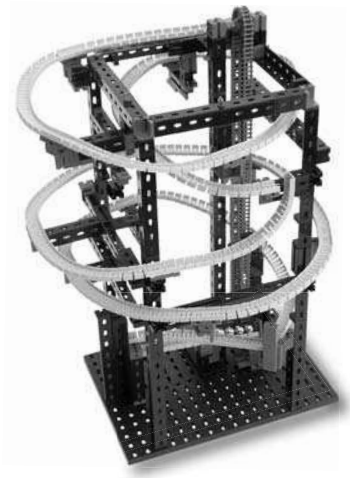


Tip:
If the balls are not picked up and transported optimally by the elevator, you can readjust the position of the ball magazine.

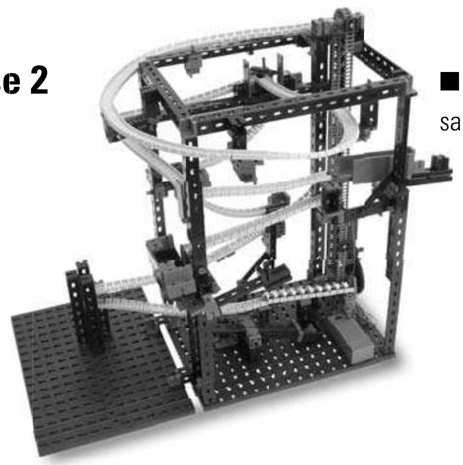
Obstacle course 1

■ This model is particularly suited for providing initial experience with the obstacle course for balls.

The balls are transported to the top by the elevator and then roll through the obstacle course back to the ball magazine.

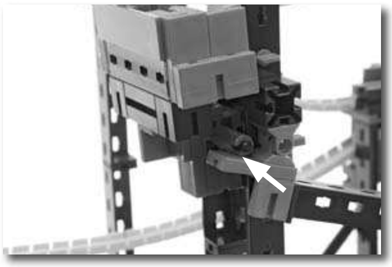


Obstacle course 2

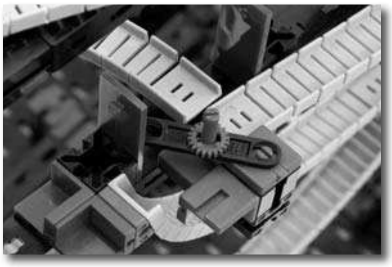


■ This model includes various effects. A few preparations are necessary before starting the obstacle course to ensure that these effects function properly.

1. Hook the ball container into its upper position as shown in the illustration.

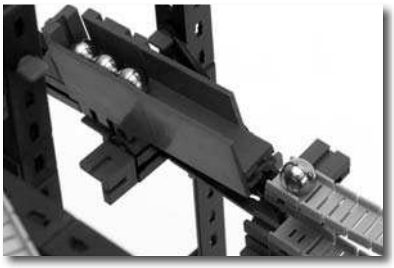


2. Set the gate on the model to the position shown in the illustration.
3. Place a block in the built-in catapult.



Now you can fill the magazine in front of the elevator with balls and start the elevator.

The balls first roll through the gate and then into a ball collector. As soon as all six balls are in the collector, it tilts downward.

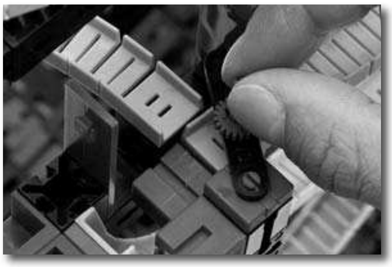


Tip:
If the collector tilts too soon or too late, you can correct it by moving the block located behind the collector as a counter weight. The closer the block is to the collector, the quicker the collector tilts.

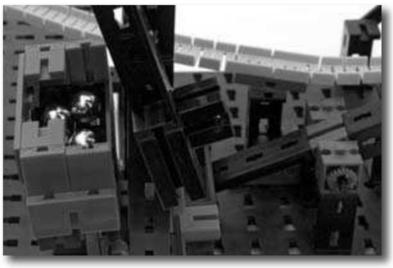
The balls then roll into the ball container, which falls down, actuating the catapult.

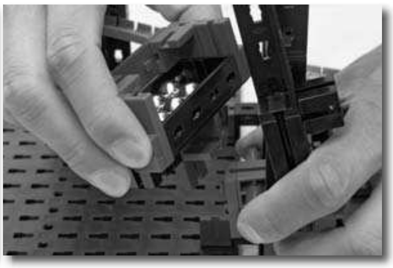
Tip:
If the ball container does not fall down correctly, you can adjust the lock by moving the block attached to the lock as a counter weight.

Now move the gate to the other position to prevent further balls from rolling into the collector. The balls then roll down along a different route.



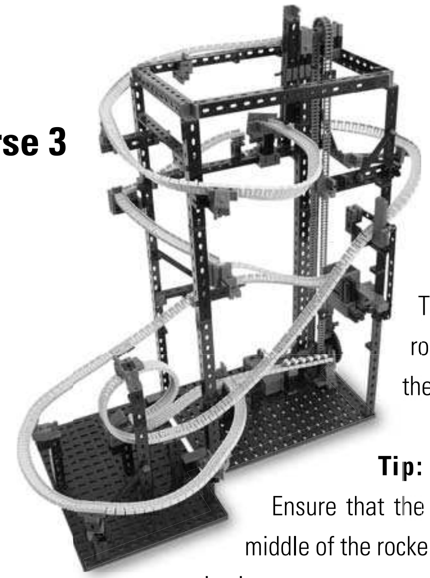
Now you can remove the ball container and refill the magazine in front of the elevator with balls.





Then you can prepare the container and catapult for the next round.

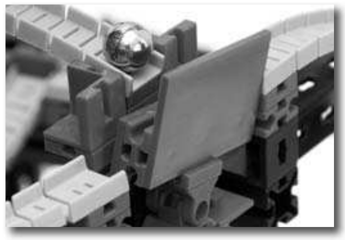
Obstacle course 3

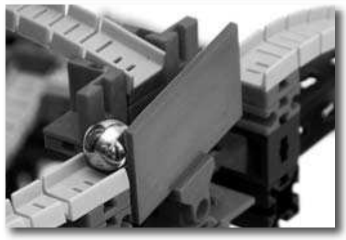


■ This obstacle course is the largest model in this set and contains the most obstacles and effects.

The ball first hits a pendulum and then rolls into an automatic gate, which routes the balls alternately to the right and left.

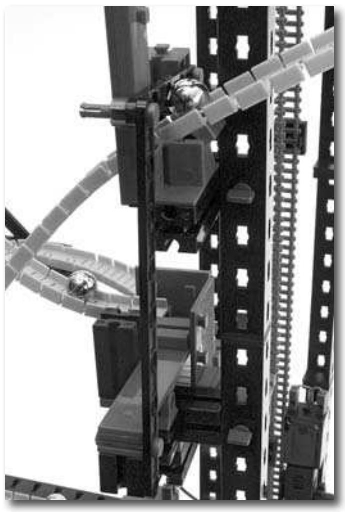
Tip:
Ensure that the joint block is located precisely in the middle of the rocker and that the gate moves easily. Otherwise it may not operate correctly.

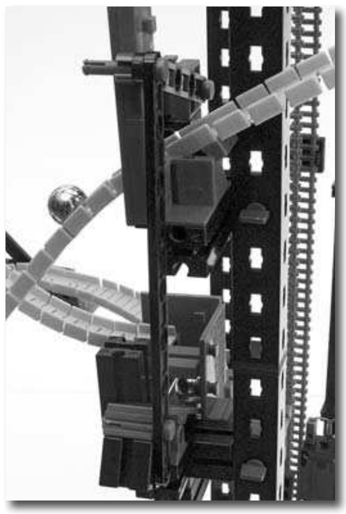




Then the ball stops in front of a barrier. The next ball is routed by the gate in the other direction and actuates a mechanism which opens the barrier. The path through the loop is then free for the first ball.

Tip:
Ensure that the rocker and barrier both move freely.





Further tips:

- Naturally you can develop your own obstacle course with the set. Certainly you can work out other ingenious designs and other fascinating obstacles and effects.

- If the flexible tracks are bent too much after disassembling the model, you can straighten them by clamping them on the base plate for a while. This reduces the bending.