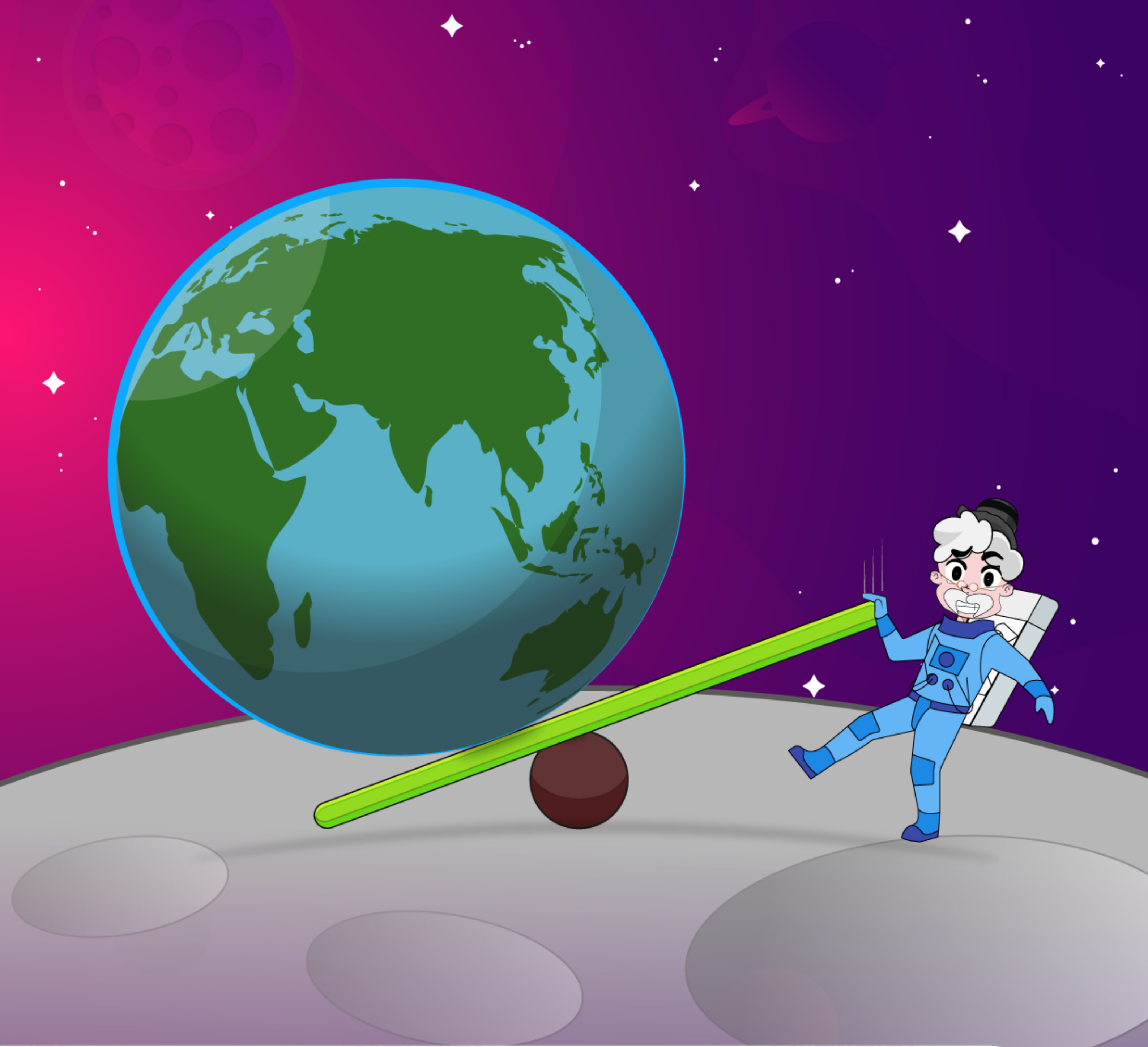


WORK POWER AND ENERGY

ARPHYMEDES

James Prescott Joule (1818-1889)

Made a profound impact on our understanding of heat and conservation of energy.
James Prescott Joule was an English physicist, mathematician and brewer, born in Salford, Lancashire. Joule studied the nature of heat and he discovered that heat and mechanical work are related, which means that energy can be changed from one form to another. This led to the law of conservation of energy, which says that energy cannot be created or destroyed, only transformed. The unit of energy, called the joule, is named after him. Joule made other important discoveries too, like understanding how electricity, passing through a resistor, produces heat. His experiments were published in 1843. Some people didn't believe Joule's work at first because it depended on very precise measurements, which were not common in his time. But Joule's experience in brewing and his access to practical technology helped him. Joule's experiments matched the theories of another scientist named Rudolf Clausius.

Fig. 35

Rudolf Clausius (1822-1888)

Heat energy will always flow from something hot to something colder.
Rudolf Clausius was a German physicist and mathematician who is considered one of the central founding fathers of the science of thermodynamics. In his most important paper, "On the Moving Force of Heat", published in 1850, he first stated the basic ideas of the second law of thermodynamics. The second law of thermodynamics tells us that things in the universe tend to become more disorganized over time.
It's like when you clean your room, but it gradually gets messy again.
This law says that heat energy will always flow from something hot to something colder, and it won't naturally go in the opposite direction. It also tells us that it's impossible to completely convert heat energy into useful work without losing some energy along the way. Basically, the second law reminds us that there are limits to how efficiently we can use energy in our everyday lives.

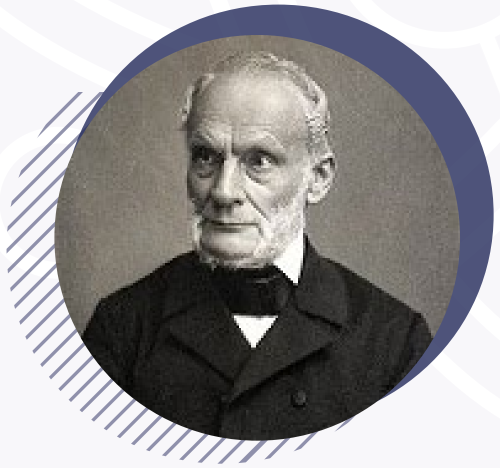


Fig. 36

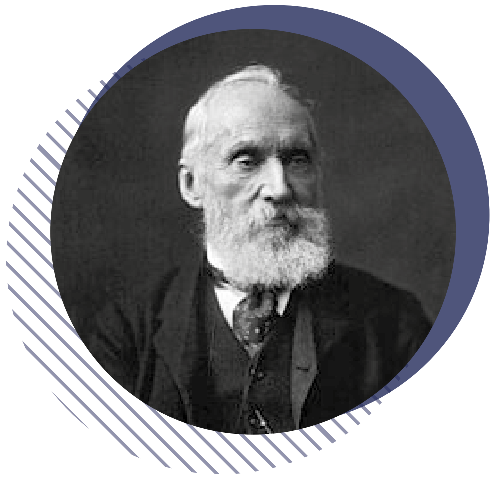


Fig. 37

William Thomson, 1st Baron Kelvin (1824-1907)

Existence of the coldest possible temperature (absolute zero). William Thomson, also known as Lord Kelvin, was a mathematician, physicist, and engineer from Belfast. He was a professor for over 50 years and made important discoveries in mathematical analysis of electricity and thermodynamics. Lord Kelvin played a big role in bringing different branches of physics together and making them work as a team. He received a special medal from the Royal Society and even became a member of the House of Lords. To honor him, we use the unit "kelvin" to measure temperature. Kelvin is also known for determining of the correct value of the coldest possible temperature as approximately −273.15 degrees Celsius. Lord Kelvin also had a role in the development of the transatlantic telegraph cable, which enabled faster communication between Europe and North America.

On this page you can find some proposals for projects that you can make at school or at home. There are even more on the accompanying webpage.

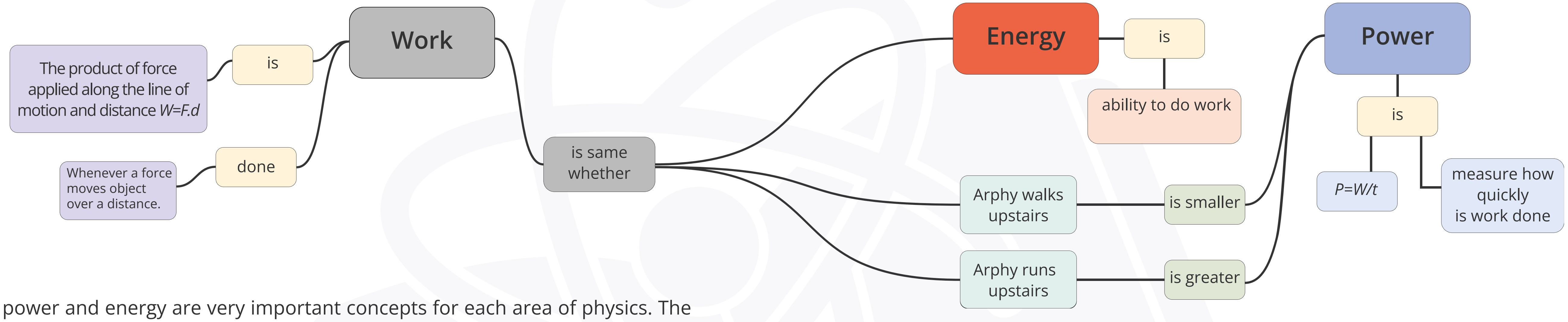
Project proposals:

1. Compare the efficiency of various devices used for boiling 0,5 l of water.
2. Does using different light source save energy? This information is important to reduce the monthly payment for electricity as it is a significant item of family budget.
3. Compare the efficiency of different appliances at home.
4. Make your own solar refrigerator and oven. If you ask your parents, or better grandparents, they can tell you more about the ways they kept food fresh in warm weather.
5. Test your classmates trust in physics using the law of mechanical energy conservation.

Technical applications:

Energy changes form whenever it is used to do work. When energy changes form it is called energy transformation.
Energy transformations occur everywhere in the universe. It happens all the time, that is, because energy cannot be created or destroyed.
What are energy transformations we meet daily in our lives?

Work, Power, Energy.



Work, power and energy are very important concepts for each area of physics. The tricky thing is that these terms are so often used in everyday life, that it gets up mixed with the meaning in physics.
In physics, a force does work when it acts on an object that moves through a distance, and there is a component of the force along the line of motion. We dealt with forces in detail in the Dynamic chapter. Now let Arphy explain you the terms work, power, and energy with following examples and animations.

Work

$W = F_x(x_f - x_i)$

Watch the animation with Arphy pushing the cart.

Work done by Arphy pushing the cart from A to B

$$W_{AB} = F_{Arphy}(x_B - x_A)$$

x_B - final point

x_A - starting (initial) point

$(x_B - x_A)$ - distance done - d

Your comments, question, observations.

Arphy has a friend willing to help him pushing the cart. Watch the animation. The work done will be calculated as follows.

$$W_{AB} = (F_{Arphy} + F_{friend})d$$

Your comments, question, observations.

There was a disagreement between Arphy and his friend, while pushing the cart. They both act with the same force on the cart. Watch the animation.

$$W_{AB} = (F_{Arphy} - F_{friend})d$$

They both act with the same force, but as you will see the result is that the cart does not move.

$$W_{AB} = F_{Arphy}d$$

Your comments, question, observations.

Now Arphy pulls the cart at different angles. but with constant force. Watch the animation.
Arphy is pulling with constant force, at an angle θ, with the direction of motion, the work done by this force is

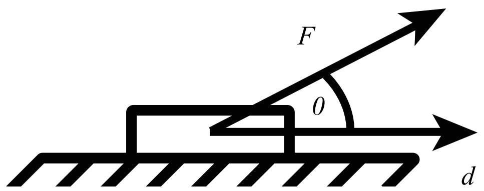
$$W = F_x (x_f - x_i) = (F \cos \theta)(x_f - x_i)$$

We must calculate the component of the force along the line of motion. We can do that using Pythagoras theorem or trigonometric function cosine. The values of most often appeared angles are in the table.

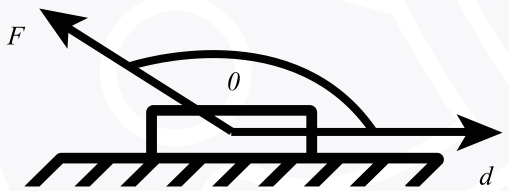
Angle (degrees)	0	30	45	60	90	120	135	150	180
cos	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	-1

Looking at the table, there are 4 options.

1. Work is positive at angle from 0 ° to 90 °.



2. Work is negative if this angle is from 90° to 180 °.

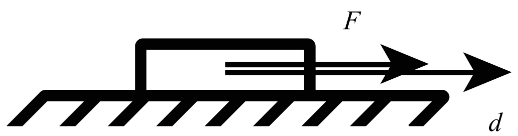


One example is friction force always acting against the direction of movement.

$W = Fd \cos(180°)$ | $W = Fd(-1)$ | $W = -Fd$

But in our examples, we used the cart with wheels, where the friction force could be neglected.

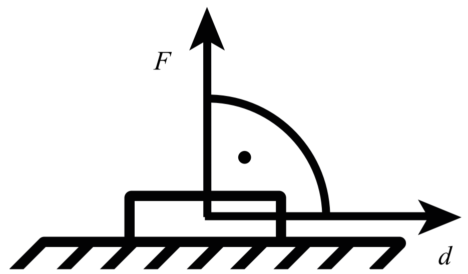
3. Arphy does maximum work, if force is in the direction of the displacement.
In that case $\cos\theta = \cos 0° = 1$. It is also the reason, why we rather push then pull, when something is really heavy. By pushing we can make the angle between the force and displacement closer to 0°.



$W = Fd \cos 0°$
we know that cos 0°=1
| $W = Fd(1)$ | $W = Fd$

4. If force is perpendicular to the displacement, no work is done.

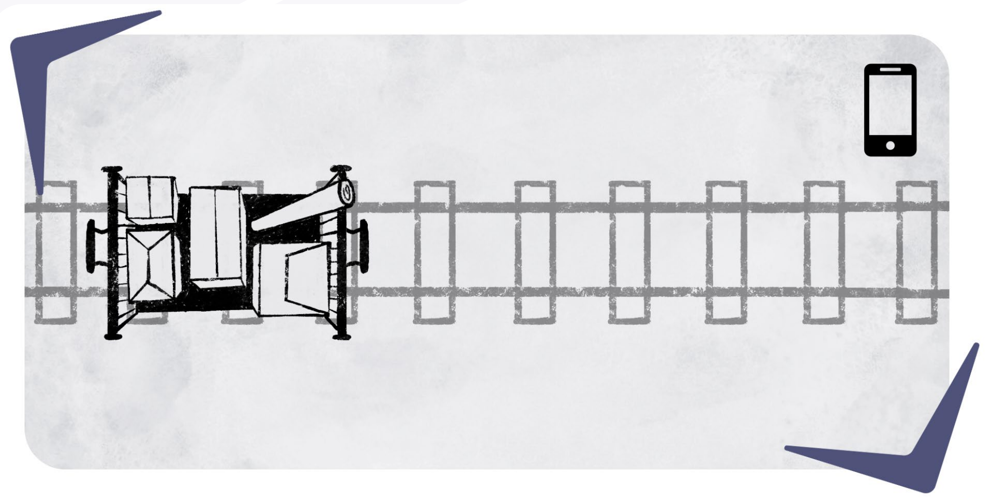
Arphy stands still with a heavy bag, no work is done on the object. Although Arphy may become tired after standing for a long time, it does not involve the physics concept of work. When you sit at the table and study hard, from the point of physics you do not do any work, except for turning the pages, or writing the notices.



The equation to remember is:

$$W_{AB} = Fd_{Arphy}(\cos\alpha)d$$

Your comments, question, observations.



If there is more than one force along the line of motion, we must make the sum of all forces and then calculate the work of the net force. (In previous example we made it easier by using wheels, so that we can neglect friction – another example of simplification. Remember that we can do it as long as the result of the calculation is consistent with the observation.)

Since work is the product of force and distance, it is measured in units of newton metres. 1 newton metre (N•m) = 1 joule (J).
The amount of work is one joule when a force of one newton displaces a body through one metre in the direction of the force.

Remember following:

Only forces directed along the line of motion of an object do work on the object.

For a force to do work on an object, the object must move. It is somewhat different from the everyday use of the word work. When studying hard for school, the only work done as the term is understood in physics is in moving pencil or turning the pages of book.

Energy

Where does the ability to work come from?
We eat, feed the car with petrol, feed dogs, horses....
For bodies to be able to do the work when forces interact, they must gain energy.

Energy is very important idea in science. The concept of energy was unknown in the time when Isaac Newton lived. It was not discussed until the 1850s. The universe is made up of two things: matter and energy. Matter is what we can see, touch, and feel - it has mass. Energy, on the other hand, is more abstract. We often notice energy when it is doing something. For example, when an apple falls and hits us, that is energy in action. Or when the Sun's energy heats up water. Energy is like the ability of something to do work. It is a measure of how much capacity something has to get things done. When work is done, energy is used up. So, work and energy are connected. There are different kinds of energy, but they all fall into two main categories. One is kinetic energy (KE), which is linked to the motion of an object. The other is potential energy (PE), which is linked to how objects are separated or positioned. It is like stored energy waiting to be used. You might have also heard of other forms like thermal energy, nuclear energy, or wind energy...

Kinetic energy

From the previous chapter about forces we know that whenever net force is not zero, there is an acceleration.
Pushing, or pulling the cart from point A to B, work was done by constant net force. Using the formulas for force
$F=ma$ and speed for the linear motion with constant acceleration $v=at$

$$W = Fd = mad = ma \frac{1}{2} at^2 = \frac{1}{2} ma^2t^2 = \frac{1}{2} mv^2$$

It means, starting from point A with zero speed, in the end the cart will have kinetic energy

$$KE = \frac{1}{2} mv^2$$

If the cart has some speed in the beginning at point A - v_A and the speed at point B will be v_B, the work done by Arphy will be then

$$W = Fd = \frac{1}{2} mv_B^2 - \frac{1}{2} mv_A^2 = KB_B - KE_A$$

And this is called work-energy theorem. The work done when Arphy acts with some force and moves cart from A to B is the kinetic energy in point B minus kinetic energy in point A. If the work is positive, then kinetic energy increases, if it is smaller than zero, kinetic energy decreases, if the work is zero, then there is no change in kinetic energy. There is another important law: The law of energy conservation, it is a rule that states that energy cannot be made or disappear. Instead, it can transform from one form to another. We will deal with this law later.

Potential energy

An object can store energy because of its position in the gravitational field of Earth. The energy that is stored and held in readiness is called potential energy, because in the stored state it has the potential to do work.

Let us now derive an expression for the potential energy associated with an object at a given location above the surface of the Earth.
Arphy lifted an object of mass m from the ground to height h. We assume the lifting is done slowly, with no acceleration, so the force applied by Arphy is equal in magnitude to the gravitational force mg on the object. The work done by Arphy is:

$W = F\,h$, *where h is distance* | $W = mgh$ *and it is equal gained potential energy PE*

The unit of gravitational potential energy is Joule, the same as the unit of work and kinetic energy. Potential energy, like work and kinetic energy, is a scalar quantity. This equation is valid only for objects near the surface of the Earth, where *g* is approximately constant. (The assumption that g is constant is valid if the vertical displacement of the object is small compared to Earth's radius.)

Following example will help us understand connection between kinetic and potential energy.
Example 7
Arphy throws a stone upwards from the ground (point A) with some initial speed. In the opposite direction to increasing height acts gravitational force. At some point (B) the stone will come to halt. Can we find out the height it will come to?

Easier way of calculation.
At point A the stone has only kinetic energy

$(1/2)\,mv^2$

In the highest point B stone stops and so has no speed and no kinetic energy, all was transformed into the potential one.

$(1/2)\,mv^2 = mgh$

The more precise calculation is as follows.
The work done by gravity when moving from point A to B is therefore

$W_{AB} = -mg\,(y_B - y_A) = -mgh \qquad W_{AB} = KE_B - KE_A$

In point B comes the object to a halt thus $KE_B = 0$

And so $-mgh = 0 - KE_A = -(1/2)\,mv_A^2$.

Hence $h = v_A^2/2g$.

Let us use the above written to formulate work-energy theorem $-mg\,(y_B - y_A) = KE_B - KE_A$

We will rearrange it $mgy_B + KE_B = mgy_A + KE_A$

For *mgy* - gravitational potential energy - we will use the term PE. Thus we get

$PE_B + KE_B = PE_A + KE_A = PE + KE$

The sum of *PE* + *KE* is called mechanical energy and it is conserved in some specific cases. We can use it whenever the work is done by gravitational force.

POWER

The definition of work says nothing about how long it takes to Arphy to carry shopping bag home on the third floor. But for sure when he decided to run upstairs, he felt more tired. To understand this difference, we need to talk about a measure of how fast the work is done – power. Like work and energy, power is a scalar quantity.

Power, by definition, is **the rate of doing work or of transferring it.**

$$P = \frac{W}{t}$$

Power is measured in units of joules per second (J/s). The concept of power is so important that the unit of power is given its own name, the watt W. 1 W = 1 J/s.

When utility companies sell electric energy, they measure the energy sold in kWh. They do this because joule is a very small and inconvenient unit for their purposes. 1 kWh = (1000J/s) (3600s) = 3,6 x 106 J. Therefore, on the bill for the electricity we read the amount in kWh. We hear almost daily about the necessity to save energy, use alternative sources. If you are interested in being able to calculate the amount of energy you use in your household and which appliances are the most energy consuming, look at the webpage. There are spreadsheets in each country to help you make some quick estimations of energy consumption. However, we prepared some alternative projects for you.
But firstly, as we have now enough knowledge there are examples connected to work, power and energy.

Example:
Arphy pushes a 10 kg toy car with a constant velocity over a distance 10m.
How much work he did?
What is the final kinetic energy of the car?

Solution

Example:
Arphy lifted 10 kg box of chocolate with a constant velocity to the height 10m.
How much work he did?
How much energy is stored in the box (in the gravitational field).

Solution

Example:
Arphy dropped ball (10kg) on the floor from the height 10m.
How fast was the ball moving before it hit the floor?
How fast would twice as massive ball be moving when dropped from the same height?

Solution

Example:
Arphy dropped a ball (10 kg) from the height of 30m (10th floor approximately). It bounced off a trampoline and reached 15 m on the return path upwards.
How much energy was "lost" and where do you think it "went"?

Solution

Example:
Why does the human body need energy?
Even if we do no physical or mental work, we need energy - for breathing, heart rate, maintaining body temperature – we call it basal metabolic rate.
We can calculate it.
Women: (1.85 x height in cm) + (9.55 x weight in kg) - (4.67 x age) and add 655 = basal metabolic rate in kcal.
Men: (5 x height in cm) + (13, 6 x weight in kg) - (6.7 x age) and add 66 = basal metabolic rate in kcal.
The unit kcal was used before and is still used in some diet recommendations. 1 kcal x 4.18 = 1 kJ

We need daily around 6 - 7,500 kJ, which means the power 69 to 87 W $\left(P = \frac{W}{t} = \frac{6\ 000\ 000\ J}{24\ 3600\ s} = 69\ W\right)$

By an easy job we spent about 10 000 kJ (Power - 120 W) and by doing sport up to 20 000 kJ (Power - 240 W).
The energy comes from food we eat.

Example:
The body needs about 10 MJ per day. Imagine that we supply such an amount in the form of food, but in addition, go on a cycling tour, cycling for two hours. The metabolic value corresponds to this activity is 7.6 W.kg-1. How much fat will burn 50 kg person if the energy equivalent of fat is 38.9 kJ / g.
W1 = 10 000 000 J
W2 = 7,6 W / kg x 50 kg x 7200 s = 2 736 000 J.
Together W1 + W2 = 12 736 000 J.
The person will loose 12 736 000 J / 38 900 J / g = 70 g of fat

Example:
We have a class with 30 students. What is the power of the whole class, when they do an easy job and how much lignite coal with calorific value 17 000 KJ per kg will be necessary for the same power amount?
Easy job (e.g. sitting in the class and listening to the teacher) means 120W.
30.120W =3,6 kW. In one hour 3,6 kWh and that means 3600. 3600 Ws=12 900 kJ

It means we will need $\frac{12\,900\ kJ}{17\,000\ kJ} =$ 0,76 kg per hour.

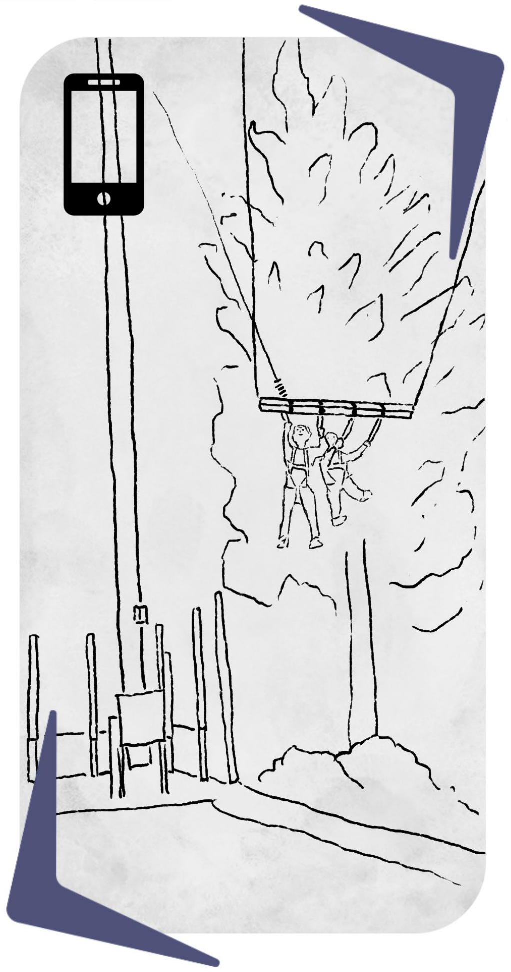
Example:
Alpine carrier weighing 80 kg, will carry 70 kg on a route of 7 kilometers in 3 hours. What is his power? Compare it to horse power of 746 W.

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{mgd}{t} = \frac{(80+70)kg.10\ m.s^{-2}7\ 000m}{3.3600\ s} = 972{,}2\ W$$

But about twice a year, the owner of the alpine hut rents a helicopter, which brings him dozens of beer kegs, wood for heating and the like. The rest of daily necessities are carried on the backs by carriers. When calculating the payment for kilograms the carriers are more expensive than a helicopter.

Example:
This example is from Funny Park Oravská Lesná. Watch the video first. Your tasks will be:

1. Find out the potential energy the girls have at the beginning of their the swing?
2. What will be their maximum speed at the lowest position?
3. What is the "energy loss" after reaching the maximum height on the other side and where is the "lost" energy?



Do your own calculation following the steps

Estimate the height of the swing. There is a man operating the swing. Considering an average height of a man to be 180 cm – the height of the swing is: ____________________

The formula for calculation for the potential energy : ____________________

Kinetic energy: ____________________

The law of mechanical energy conservation: ____________________

The speed at the lowest position: ____________________

Using the same way of estimation determine the highest point on the other side: __________

Calculate the potential energy on the other side of swing: ____________________

The energy loss was: ____________________

The lost energy was transformed into: ____________________

Now when you did the calculation, you can test your classmates' trust in physics. Do it only under a supervision of a teacher or a parent.
Material needed: 2 liter PET bottle, strong twine, about 3-4 m and a place to hang the bottle.

Procedure:

- Hang the bottle in such a place that the bottle can swing freely in a vertical plane without hitting anything.
- Fill the bottle with water and hang it.
- Ask your classmate to stand so that the bottle touches his chin when the string is pulled tight.
- Warn him not to move.
- Stand behind him, pull the bottle towards his chin and release it.
- Similar to the swing in the example, the bottle passes through its lowest position, deflects to the opposite side from the classmate and returns to him.
- Make sure the classmate doesn't move at all.
- This is an example of the conservation of mechanical energy in praxis. The maximum point the bottle can reach is the starting position.

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Student Book

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