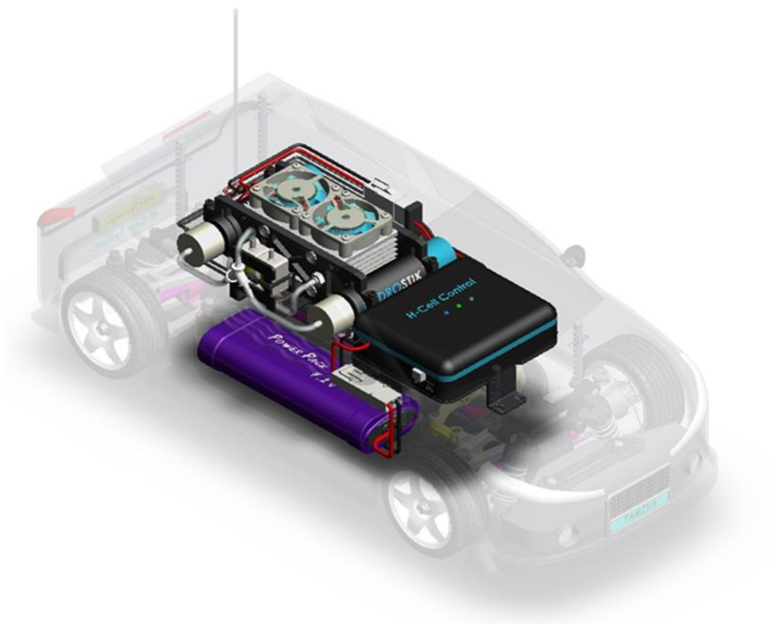
1 - CAR SYSTEMS

How does the car work in general?
How can we describe its different parts and its possible uses?



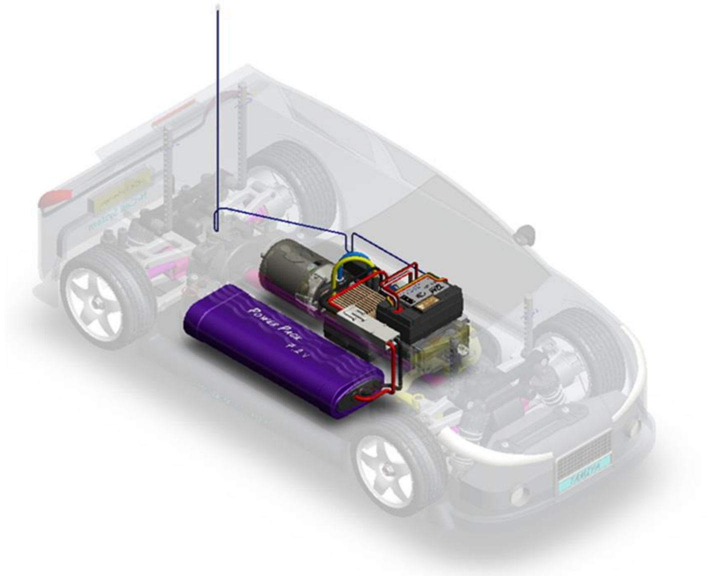
1 - CAR SYSTEMS

How does the car work in general?
How can we describe its different parts
and its possible uses?

1.1
Steering
And Propulsion

Complete Experiment

Time Required: **1h**



Necessary equipment and resources:

Horizon equipment:

- Basic FCAT car on track
- Radio control transmitter

Other equipment:

- Oscilloscope
- the use of a multimeter is recommended

Objectives:

In this activity, we will use the car with its remote control and read some documents to understand the principles that control the car's propulsion system.

We will then use the SysML language to describe the radio control's operating system, in the form of graphs.

We will measure the remote control's signals.

Controlling movement, without a physical link between us and the object...

Controlling propulsion remotely

We can control an object such as an electric car remotely, though electromagnetic waves that travel through the air. To do this, the control system relies on a handheld transmitter that controls propulsion and on a receiver that is fitted inside the vehicle.

Two things are necessary for this to be a successful control system. First, the system should control only our race car, without interfering with that of another competitor. And second, the system should have a sufficiently long range to prevent us from losing control of the car when the race takes it too far away from the driver.

Wireless communication

When we talk to each other, we communicate without resorting to specific equipment; the speaker's mouth emits a sound and the listener's ears collect that sound as long as they aren't too far apart. When the distance becomes too great, we are forced to rely on other means, such as voice amplification, or transforming sound to another form of energy so that it can travel, silently, through the air.

In order to control the car, we must communicate certain operational commands without actually speaking to it. Many things in our daily lives now communicate without a physical link, such as mobile phones, a TV set and its remote control, a wireless joystick for a video game, a Wi-Fi connection between a computer and a printer, etc.

Electromagnetic waves as a type of language

Electromagnetic waves, which are invisible to the naked eye, are best imagined as waves that travel through the air between a transmitter and a receiver. They allow us to communicate with one another without having a physical link between us.

The general aspect of these waves depends on the command that the driver sends to the car, and each wave shape is specific to a single driver's transmitter, thereby preventing other cars on the track from intercepting the message. It's as if each transmitter speaks its own language, a language that only its specific receiver can understand.

Our activity:

The purpose of this activity is to observe and describe the nature of the link between the propulsion command transmitted by the movement of the driver's hand and the reaction of the car as it's driving around the track.

1.1.1

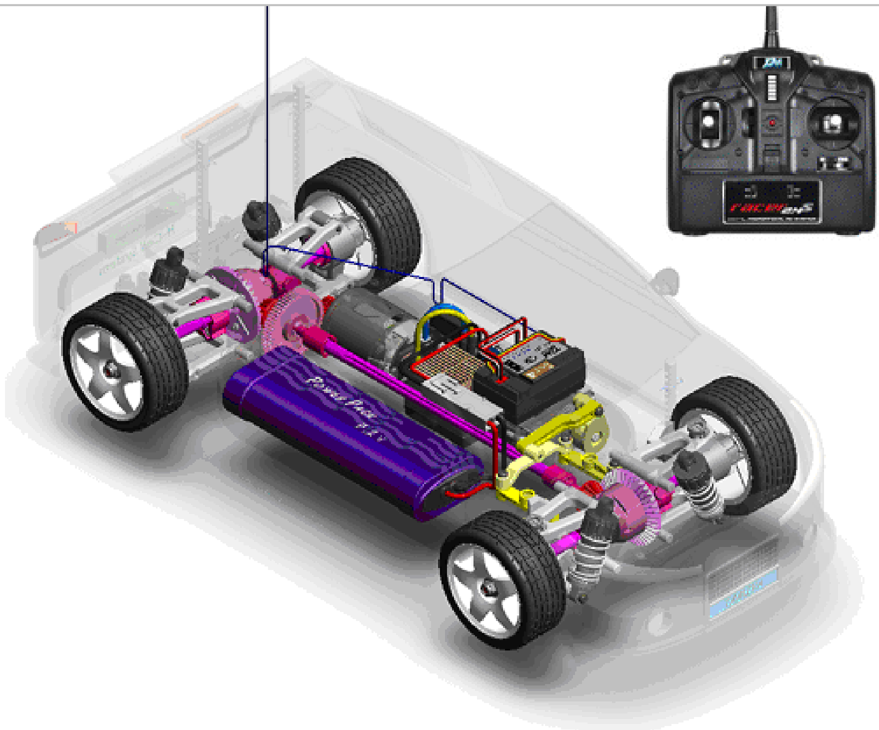
Time Required: 20 min

0:20

Read the car's documentation and observe the system while it’s working, as you use the propulsion system.

Question:

On the drawing of the RC car, identify the following items: The battery, the transmitter, the receiver, and the speed controller, and explain the role that each of these items plays in propulsion control (the image may be different, depending on your model).



Item	Role
Transmitter	
Battery	
Receiver	
Speed Controller	

1.1.2

Time Required: 5 min

0:25

Question:

In general, how does the signal that makes the car move get from the transmitter to the receiver?

1.1.3

Time required: 5 min

0:30

For the transmitter and the receiver to communicate, they must use the same radio frequency. All car frequencies are within the authorised range of 2.4GHz, and many channels are available, allowing several remote controls to be used simultaneously. Depending on the model, the remote control can have one or more channels for the servomotors and the controllers.

Question:

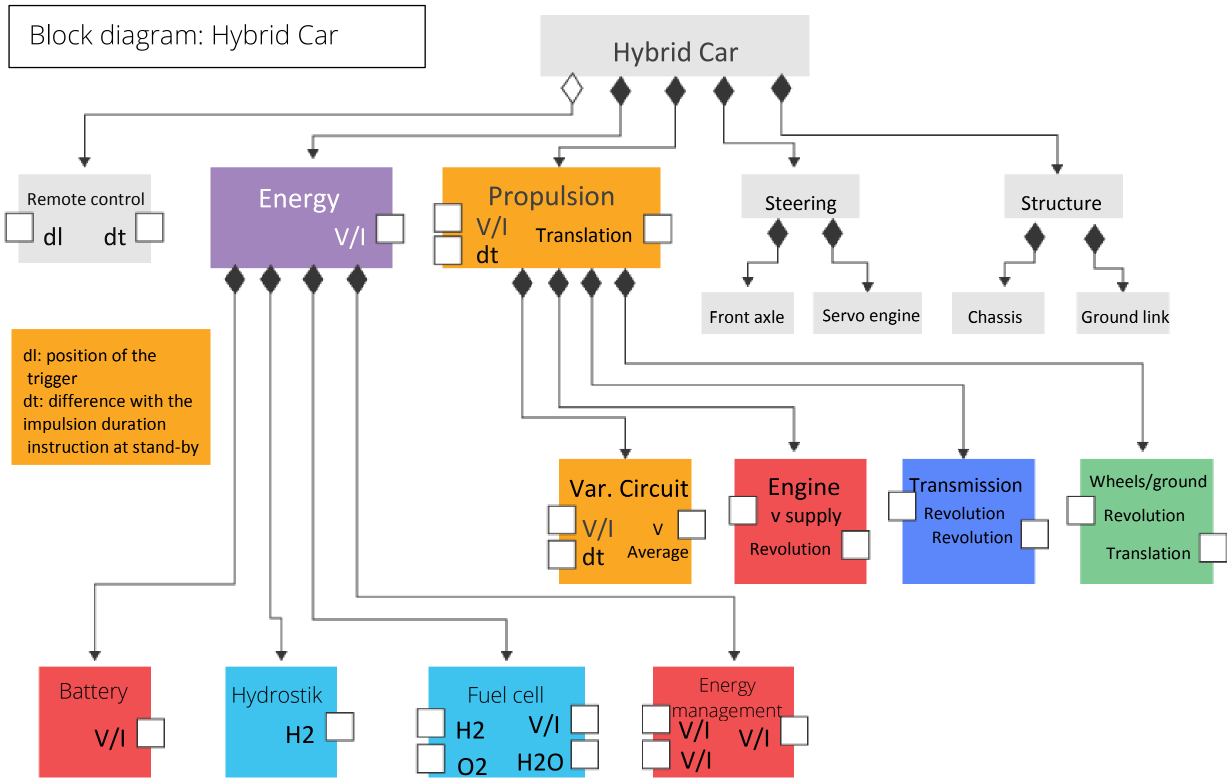
How many channels must the remote control have for a remote-controlled car?

Quartz frequency	

Time required: 10 min

0:35

Take a look at the SysML block diagram shown below:
Pay special attention to the remote control and propulsion blocks.



Questions:

A - Where does information flow at the remote control's input?

B – What form does the output take?

C - The receiver is not shown in this diagram. Draw an arrow to indicate what element of the diagram communicates with the receiver.

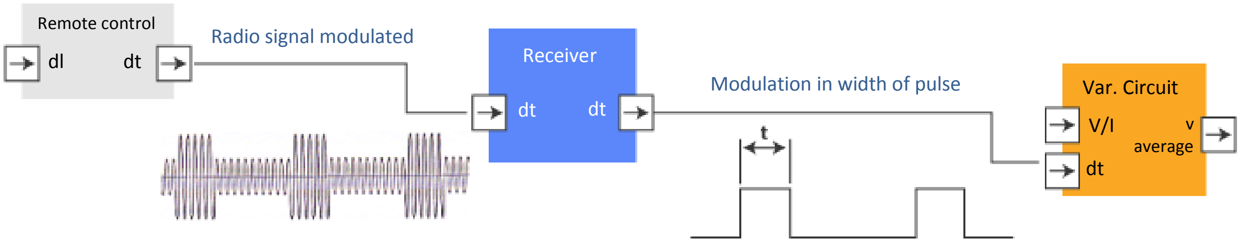
A :	
B :	
C :	

Let's consider a portion of the SysML block diagram shown below; it shows the remote control block along with the propulsion block activated by the remote control. Let's add a receiver block here.

The radio sends a signal with a frequency of 27MHz, and either the signal's amplitude (height) or frequency (width) is altered to carry the information about the duration of the signal.

At the receiver's output, a modulated electric signal is emitted that indicates the radio signal's duration.

At stand-by, when the engine is stopped, the signal's duration is *t* (which we will determine) and if the pulse width increases or decreases, the engine will run in one direction or the other.



We will now measure the command signal on the receiver to describe it entirely. At the output of the receiver, we find two channels with red, black and white threads. One is for the controller, and the other is for steering.

In this photo, one of the cables is disconnected to carry out the measurements. First, we will determine the role of each wire.

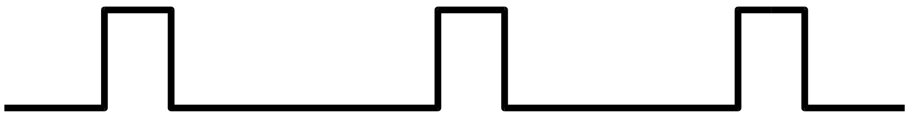
(A multimeter is recommended)

1.1.5

Time required: 20 min

0:40

We will specifically consider the control signal on the white wire.



Instructions:

A - Measure this signal with the oscilloscope and fill in the table below. Connect the ground of the oscilloscope to the ground of the battery and measure voltage values on the connector's three pins.

B - Measure the same signal for the two extreme positions of the control stick and write down what part of the signal varies. Then provide the extreme values.

A		
	Results of the measurements	**Role of this pin**
Red wire		
Black wire		
White wire		
Frequency		
Duration of high level		
Highest voltage		
B		
Signal characteristic that varies		
Extreme values		

1 – CAR SYSTEMS

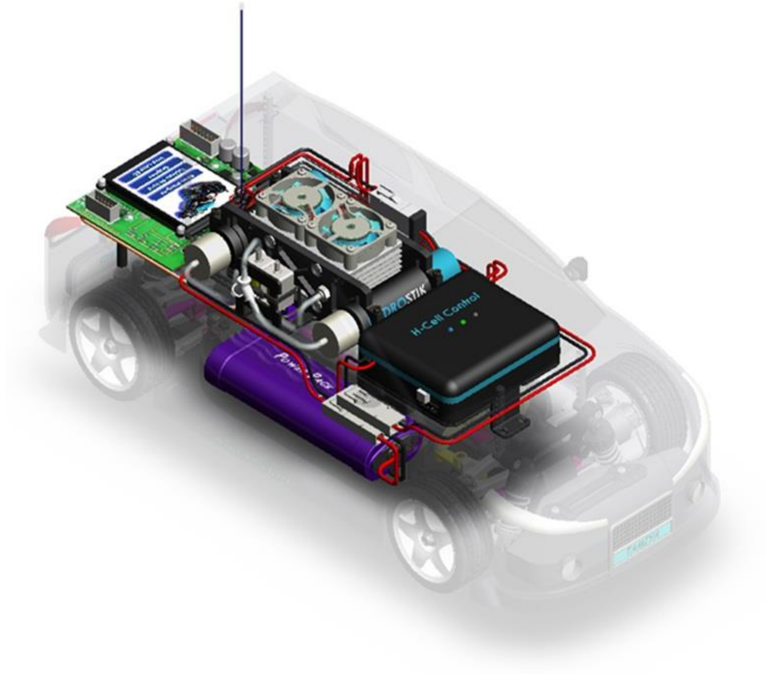
How does the car work in general?
How can we describe its different parts and its possible uses?

1.2
Using Electrical Energy to Power the Vehicle

Full study

Time Required:

1h + Additional module 1h



Necessary equipment and resources:

Horizon Equipment:

- FCAT car
- A car with a single battery in one acquisition

Objectives:

In this study, we will explore the vehicle's input and output power.

Energy...

What is it exactly?
Where is it found in our car?
In the engine? In the wires? In the chassis?

Energy is the capacity of a system to do work, or to create movement, light, or heat.

Energy is an ancient concept. Having used their own energy and the energy of animals, humans soon learned to use the energy contained in nature (first wind power, and then water mills and hydraulic power). It gives us the ability to use more and more energy through the use of machines such as power tools, steam engines and electric motors. Energy is also provided by burning fuel (such as fossil fuels or renewable energy such as hydrogen).

Since energy is necessary to any human endeavour, the availability of sources of usable energy has become one of mankind's greatest challenges today.

In purely physical terms, there is no such thing as a source of energy, nor is there energy loss or renewable energy, because:

- Energy can neither be created nor destroyed.
- Energy can only be transformed from one form to another.

The issue of storing and transporting energy is crucial in terms of human activities.

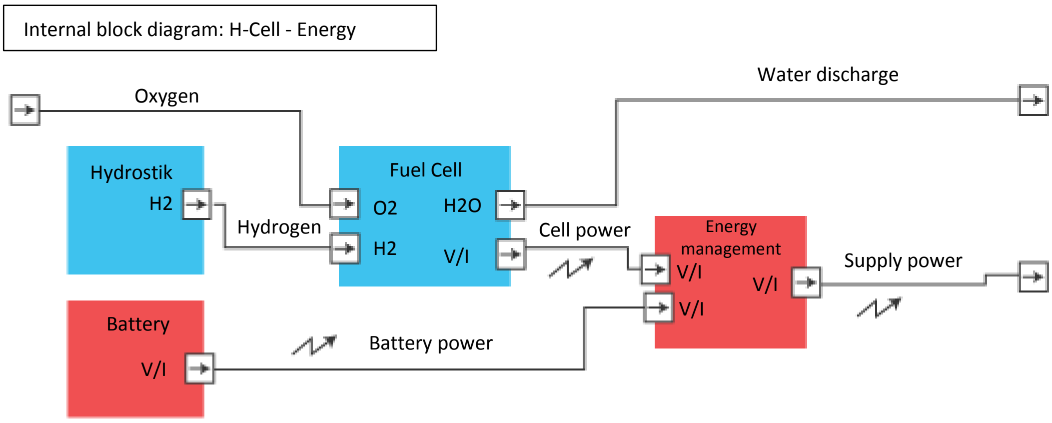
Our car will therefore rely on a "source of energy" to produce the force to overcome friction and inertia that oppose the car and make the car move forward. This "input energy" of the system is not lost, it is transformed. There is therefore also some output energy. We are going to identify these energies.

1.2.1

Time Required: 5 min

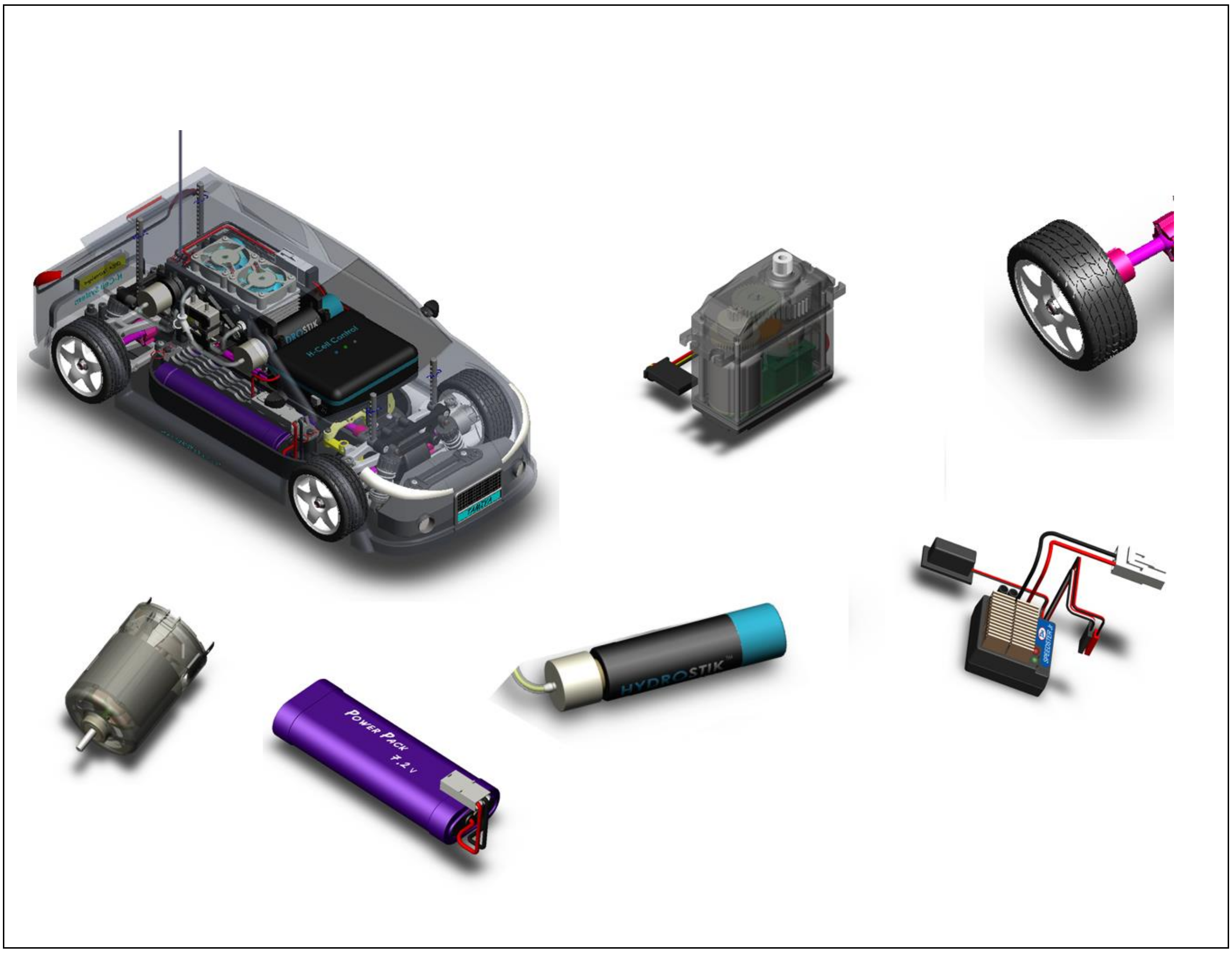
0:05

Concerning the "input" energy, our car is a bit special because this hybrid vehicle has, in fact, two sources of power.



Question:

Please identify on the next page the items in which this input energy is stored.


H-Cell Control
HYDROSTIK
POWER PACK
7.2V

1.2.2

Time Required: 5 min

0:10

Let's examine our two sources of "stored" energy.

Question:

Below, check the boxes that correspond to the form of stored energy or energies provided by both the the "Battery" and "Hydrostik Cylinders."

	Battery	Hydrostik Cylinders
Electric energy		
Thermal energy		
Kinetic energy		
Chemical energy		

1.2.3

Time Required: 10 min

0:20

Other forms of energy

Question:

Based on your research, on the Internet for instance, describe other forms of energy.

ENERGY STORAGE ITEMS

Battery, or "electrochemical cells"

Electric power is stored in the cells (chemicals in the cells store electric charge).

Depending on the technology used, the amount of energy in a given volume can vary.

Here we have a metal nickel-hydride battery or a NiMH (nickel-metal) hybrid, which is a widely-used technology.

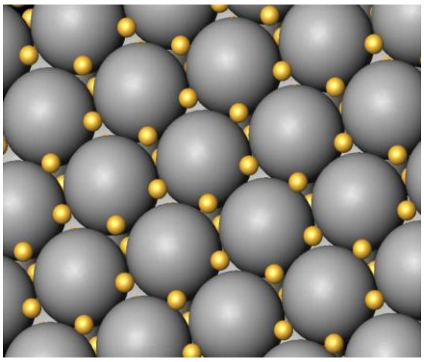
Our battery actually contains six series-connected electrochemical cells.

In our hybrid system, the battery can be charged or depleted, depending on the car's operating mode. When the vehicle is in stand-by, the fuel cell charges the battery. Therefore, at the end of the race, the battery can be just as charged as it was at the beginning.

Hydrostik cylinders

The chemical source of power is stored as hydrogen, inside the Hydrostik. Hydrogen is, in this case, stored in a low-pressure metal hydride.

The metal hydride absorbs the atoms of hydrogen, a bit like a sponge.



When the car is used, the fuel cell continuously produces energy using the hydrogen reserves. This energy is used to move the vehicle or to charge the battery.

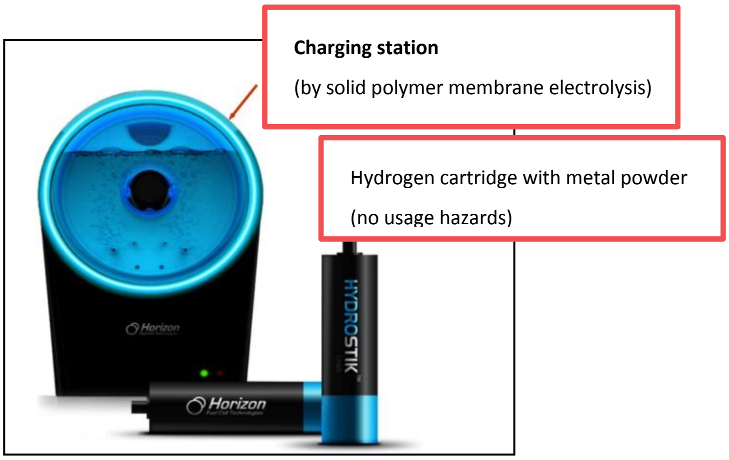
1.2.4

Time Required: 5 min

0:25

Before we can use the energy in the Hydrostiks, it has to be produced.

Hydrogen is produced from water. When energy is used to break the chemical bond that holds water together, it lets off two atoms of hydrogen and one atom of oxygen. When the hydrogen is recombined with the oxygen in a fuel cell, it releases water and energy.



Question:

Below, please describe where the energy stored in the battery and in the Hydrostik is taken from. Indicate the type of energy that is stored in this manner.

	Battery	Hydrostik
Where is the stored energy taken from?		
In which form is it stored?		

1.2.5

Time Required: 5 min

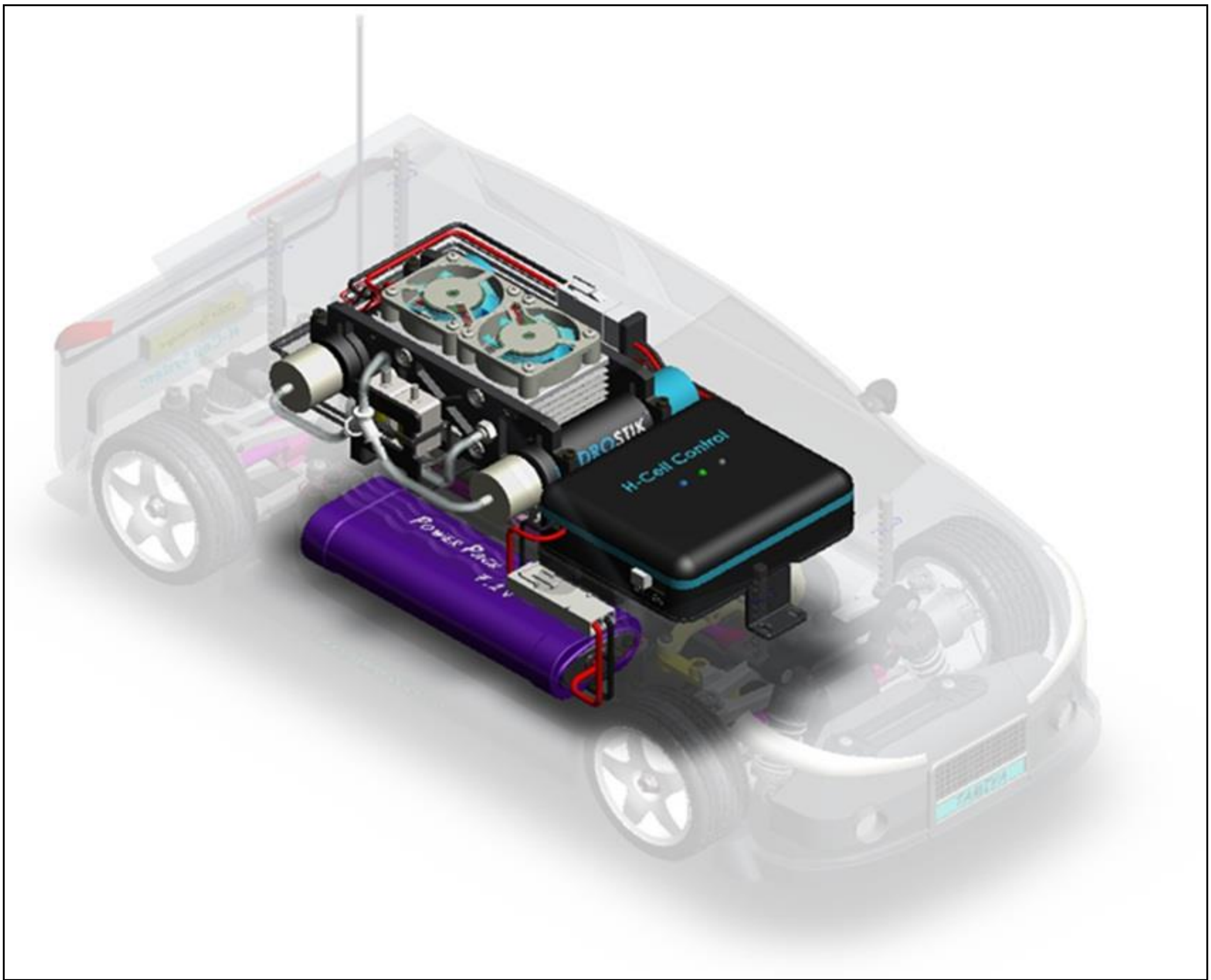
0:30

Let's observe the movement of energy within the car, from the fuel and the batteries all the way to the wheels. We describe this as "energy transport" within a given car.

Question:

Explain what is used to "transport" the various sources of energy from the Hydrostiks and the battery. In the drawing, identify the "A" and "B" zones

	A - At the battery's output	B - At the Hydrostik's output
Transported by:		



1.2.6

Time Required: 5 min

0:35

We have now identified the input energies of our system. We know that this energy is transformed into another form of energy by the vehicle's components.

Questions:

A – What is the nature of this new form of energy, and on what part of the car can we measure it?

B – Before we start moving, the car is on the ground and stopped. Once we've finished, it is still on the ground, and still stopped. Where did the energy go?

A :
B :

1.2.7

Time Required: 20 min

0:40

You will now try to quantify this energy, giving it units and figures, using the measurements taken as the car completes its lap (see the "dashboard" operational mode provided as appendix).

Question:

At the end of the lap, note the various physical values mentioned in the table below. Using the formulae, check the consistency of some of these values.

Useful energy consumed "$E_{consumed}$" (J)	Average power "$P_{average}$" absorbed by the engine (W)	Average current intensity "I" (A)	Average "V" voltage (V) (to be calculated)	Duration "t" of the circuit (s)

$E_{consumed} = P_{average} \cdot t$	$E_{consumed}$ = ________ • ________ = ______________ J
$P_{average} = V \cdot I$	$P_{average}$ = ________ • _________ = ________ W

ADDITIONAL STUDY MODULES

(Time Required: 1h)

Regarding the units that are useful to express or calculate energy…

The Joule is the standard unit of energy, equal to the work produced by applying a force of one Newton over one meter, or to the work provided by an electrical current of one Amp travelling through one Ohm of resistance during one second. Its symbol is **J**.

Energy can also be expressed in kilowatt-hours, which are commonly used in the construction business: **1 kwh = 3,600,000 J**

The Joule is also the product of power and time, but here it is given in Watts and seconds (**E = P•t**), where E is in Joules, P is in Watts and t is in seconds, or E in kWh , P in kW, and t in hours

	Water meter reading or estimation in kWh				consum. (in kWh)	price (kWh) in euros)	Amount without taxes (in euros)	local taxes	VAT	Total all taxes included in euros
	old	new	difference							
electricity meter n°531 new contract						(1)	15,98	1,53	0,96	18,47
yearly contract										
7,86€ /mois du 11/09/08 au 12/11/08							15,98			

In everyday life, approximately:

- **1 joule:**
  - is enough energy to lift one apple (100 grams) by one meter (close to the earth's surface)
  - is enough energy to increase the temperature of one gram (1 litre) of air by one degree Celsius.
- **1000 joules:**
  - the quantity of heat that a resting person lets out in 10 seconds;
  - the energy required by a child (30 kg) to climb a set of stairs (a little over three meters).
- **1 mega joule (one million joules):**
  - fifteen minutes of heating with a 1000 W heater.

It's difficult to measure energy directly. Generally, we measure other physical dimensions and use them to calculate energy. For example:

In electricity… for direct current provided by a battery, the product of the current in amperes and the voltage in volts provides the power in watts: **P = I•V**

In mechanics… in the case of linear motion, the product of the force in Newton and of speed in meters/second provides the power in watts: **P = F•v**

In chemistry… in the case of the hydrostik, the energy is in the form of a quantity of fuel (hydrogen) whose energy density in Joules/liter enables us to calculate the available quantity of energy. The energy density of hydrogen is of **10000 Joules/liter** but remember, not all this energy will be converted by the battery; only 40% will be usable, or **4000joules/l.**

1.2.8

Time Required: 25 min

0:20

Question:

Use the data displayed on the battery and the following reminders to calculate the quantities of energy stored in the car.

Reminders

1J = 1W • 1s

- **in mechanics: 1W = 1N • 1 m/s,** therefore **1J = 1N • 1m**
- **in electricity: 1W = 1V • 1A ,** therefore **1J = 1V • 1A • 1s**
- **in chemistry: 1J = 1 J / liter. 1 Liter (Hydrogen: 10000 J / litre)**

	Voltage	Capacity
Value displayed on the battery		
Corresponding inscribed unit		
(Useful unit for calculation)	**(V)**	**(A•s)**

Quantity of energy stored in the battery (J)	Quantity of energy stored in one Hydrostik cartridge containing 1 gram, i.e. 10 litres of hydrogen (J)
Comment:	**Comment:**
Calculation of stored energy:	**Calculation of stored energy:**

1.2.9

Time Required: 15 min

0:45

The energy stored in the car will therefore allow us to travel a given distance. The energy required will depend on the speed, the stresses on the car's frame, the weight of the car, wind resistance, friction, and the slope of the track.

Questions:

A - Given a force of 8 Newton with a speed of 20 km/h or 5.5 m/s, how much power is needed for the car to move?

B - Given the available energy in a Hydrostik and in the battery, determine the value of the theoretical travelling time. Convert your results into minutes, and rounding them off to the nearest minute, for the cases given in the following table.

A - Power necessary for the car to travel		
B – Run time in minutes	**In the case of a system considered to be perfect:** **No loss of energy between the storage source and the car**	**In the case of a real system:** **Considering, for instance, 40% of energy losses between the storage source and the car***
• **For the battery alone**		
• **For two Hydrostiks**		

* The value is arbitrary and an approximate, as it is derived from relatively complex studies. However, we will subsequently use simple measurements to determine with greater accuracy the size of these losses within a system.

Appendix

Measurement of the operating parameters with the dashboard

DASHBOARD
Distance covered: 80m
Measurement duration: 28s
Battery voltage: 6.7 - 7.6V
Maximum values
Speed: 25km/h
Useful current: 7A
Useful power: 50W
Average values
Speed: 7km/h
Useful current: 0.8A
Useful power: 6.2W
Consumption values
Fuel cell energy: 152j
Battery energy: 121j
Useful energy: 176j

1 – Turn on the vehicle (button next to the display)

2 – Turn on the hydrogen fuel cell (button on the control casing)

3 – Press the "dashboard" button

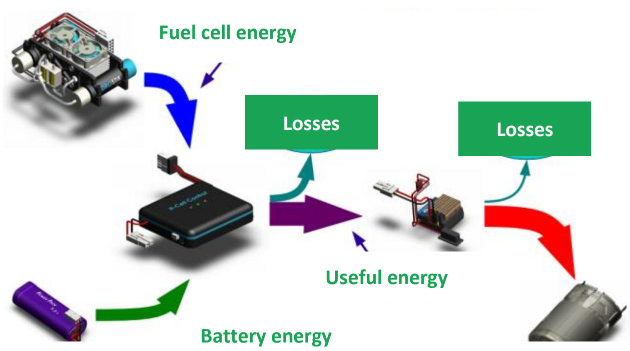
4 – Press LAUNCH ACQUISITION to start the measurements

5 – Move the vehicle using the remote control

6 – Press STOP to end the measurements

7 – Note the measured values

Measured energy



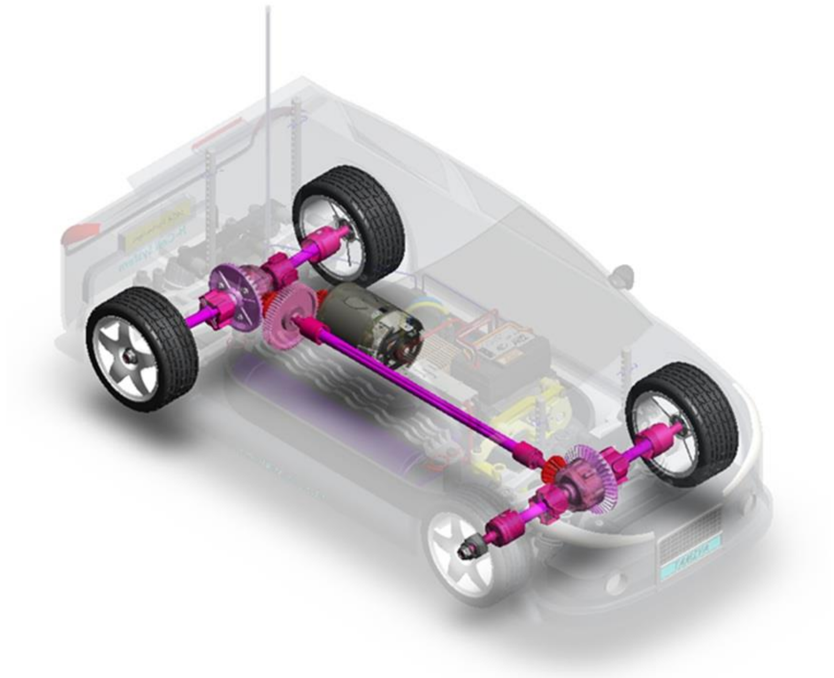
1 – Car Systems

How does the car work in general?
How can we describe its different parts and its possible uses?

1.3 Transmitting Mechanical Energy

Full study

Time required: **1h**



Necessary equipment and resources:

Horizon Equipment:

- Basic FCAT car with acquisition card

Other equipment:

- Reflecting labels
- Speedometer
- Shim of testing bench for laboratory measurements

Objectives:

During this activity, we will examine the transmission system between the engine and the wheels during movement in a straight line, in order to determine a kinetic energy "input-output" law based on actual measurements and theoretical analysis.

What is the best way to describe a moving object?

To each his own...

The way one chooses to describe a moving object largely depends on the information one would like to obtain.

For instance, in the case of our activity, we need to know how much energy is required to give our vehicle a certain speed. That is therefore the direction that our observations must take.

However, the very idea of energy may seem quite elusive at first, as energy is invisible! We will therefore proceed by steps, and try to understand what our eyes are seeing when we look at moving objects. We mustn't, however, lose sight of what we will be trying to measure later on.

Kinetic energy, mechanical energy...

Energy is in fact an abstract value that will later enable us to use basic calculations to conduct simulations of how the system will behave in terms of speed and fuel consumption, for instance. This energy translates, in the case of a linear movement of an object, into the following formula:

$$E = \tfrac{1}{2} \bullet m \bullet v^2$$

Here, we use the term kinetic energy, measured in Joules, where "m" is the mass of the body in kg and "v" is its speed in m/s.

Our car is slightly more complex than a simple object, since it includes a series of parts that move inside of it. This means that we must also take into account the sum of all these kinetic energies that are within the system.

Linear and angular velocities

This particular model seems, at first glance, to be quite complex, but we will soon learn that it is very useful. To begin with, we will accept that because all these kinetic energies are associated with the square of the velocity of each individual part, they can be linear (m/s) or angular (rad/s).

In this activity, let’s examine speeds: the speed of the car and of its internal components. We will then try to identify the links that exist between each of them. This analysis is very important and will serve as an introduction to our future observations.

1.3.1

Time required: 5 min

0:05

Preparation of the scale model for laboratory testing: the car should be in its basic FCAT version, namely, without the H-Cell system attached. The velocity measurements will be taken with a speedometer. The acquisitions card will not be used in this study.

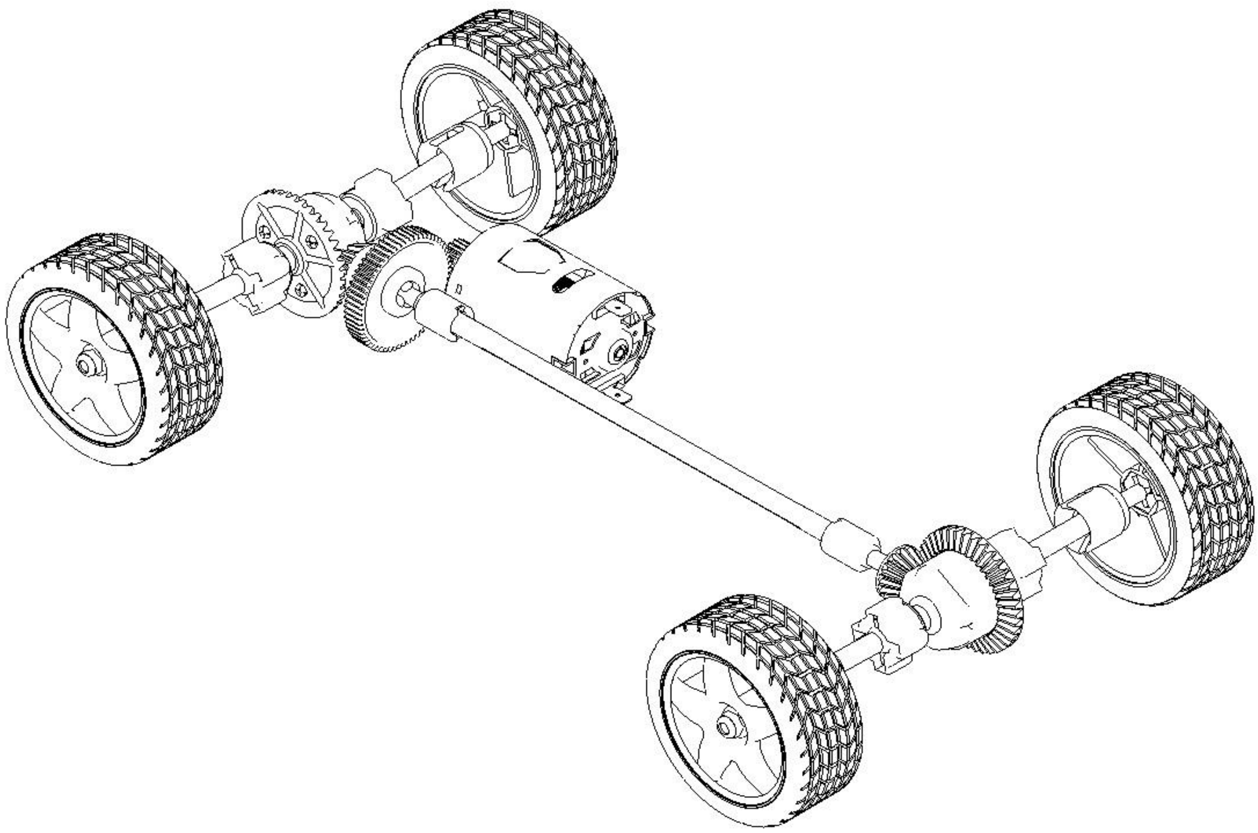
Instructions:

A – Attach a reflecting label on a drive wheel and on the transmission shaft, in order to measure velocity using a tachometer. On the image below, indicate the places that you have chosen.

B – Prop up the car, without the H-Cell system, on a shim or a bench, depending on the equipment, in order to prevent the drive wheels from moving the car forwards during the activity.

C - Ask your instructor to check the assembly before attempting to operate it.

D - Check the proper operation of the car and ensure that the tachometer is able to measure the angular velocity of the drive wheel and the transmission shaft.



1.3.2

Time required: 10 min

0:10

Angular velocities of the driving wheel and the transmission shaft

Instruction:

Carry out a test in order to measure:

- the max value of the driving wheel's angular velocity
- the max value of the transmission shaft's angular velocity

During the measurements, manually compress the shock absorber of the tested driving wheel.

In the following chart, indicate the velocities and corresponding ratio.

Draw the relevant conclusions concerning the impact of both test configurations on the measured speed report.

A - No pressure on the shock absorber/or in max speed command		
$N_{driving\ wheel}$		rev/min
$N_{transmission\ shaft}$		rev/min
$N_{transmission\ shaft} / N_{driving\ wheel}$		-
A - Pressure on the shock absorber/or in max speed command		
$N_{driving\ wheel}$		rev/min
$N_{transmission\ shaft}$		rev/min
$N_{transmission\ shaft} / N_{driving\ wheel}$		-
C - Conclusion		

1.3.3

Time required: 10 min

0:20

Interpreting the data

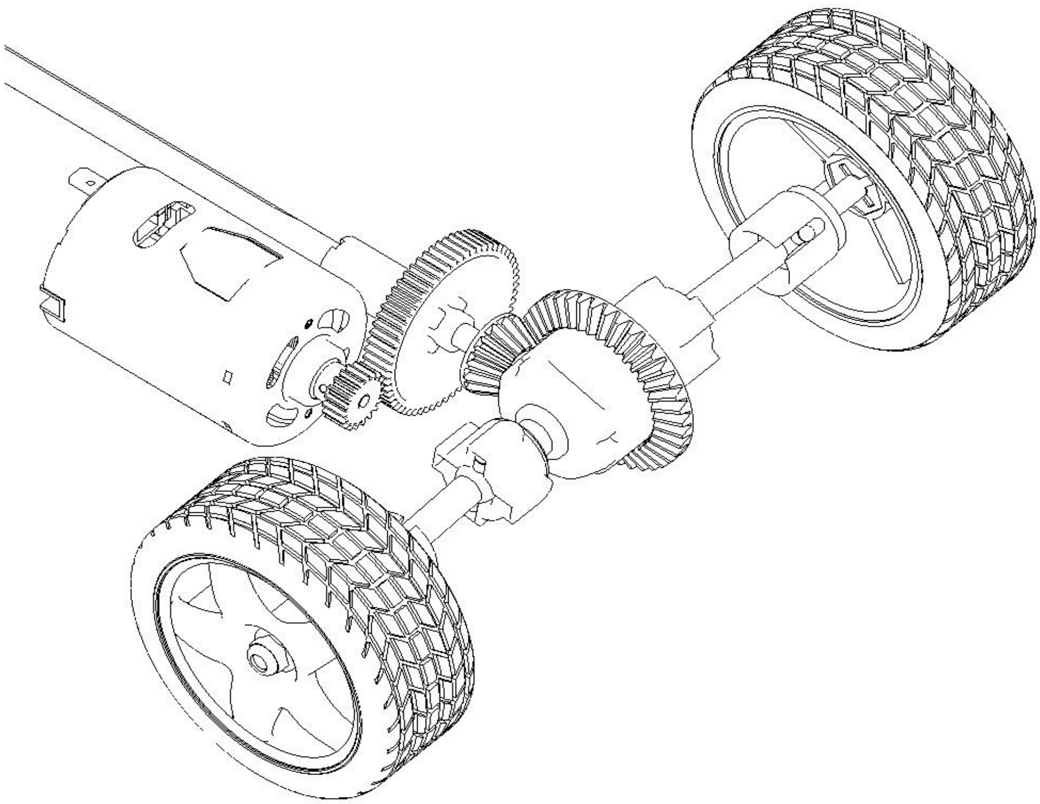
Questions:

A - The measurements show that the angular speed of the driving wheel is different from that of the transmission shaft. Having studied the information sheet for the transmission system, shade in the areas responsible for the difference between the engine and the rear wheels in the picture below.

B - Circle the method of energy transmission that is active in these areas.

C - What is the purpose of the coupling joints that drive the wheels?
(also see, for further information, the discovery booklet "3," from page 20 on)

A



B

Type of transmission in shaded areas (circle the correct answer)	**By coupling joint**	**By gear**

C

1.3.4

Time required: 10 min

0:30

Movement in a straight line or around a bend

Questions:

A - Carry out a new test, this time stopping the wheel opposite the tested wheel (for example, if you're testing the front right wheel, stop the front left wheel). Note speed values in the following table.

B - With the engine stopped, turn one drive wheel in the forward direction. What do you notice with the opposite wheel and the transmission shaft?

C - Having read the information about the car, explain, in the case of straight or turning motion, what happens in terms of angular speeds of the left and right wheels. Are they identical or different? Explain why this must be.

(also see, for further information, the discovery booklet "3", from page 11 on)

A - Manually stopped opposite wheel		
$N_{\text{driving wheel}}$		rev/min
$N_{\text{transmission shaft}}$		rev/min
$N_{\text{transmission shaft}} / N_{\text{driving wheel}}$		-

B - Manually turned wheel	
Rotation of the drive wheel?	Forward
Rotation of the opposite wheel?	
Rotation of the transmission shaft?	

C - Speed difference between the right and left wheels (yes or no)	
In a straight line?	
Around a bend?	
For what reason?	

Time required: 10 min

0:40

Transmission rotation and direction of rotation

Questions:

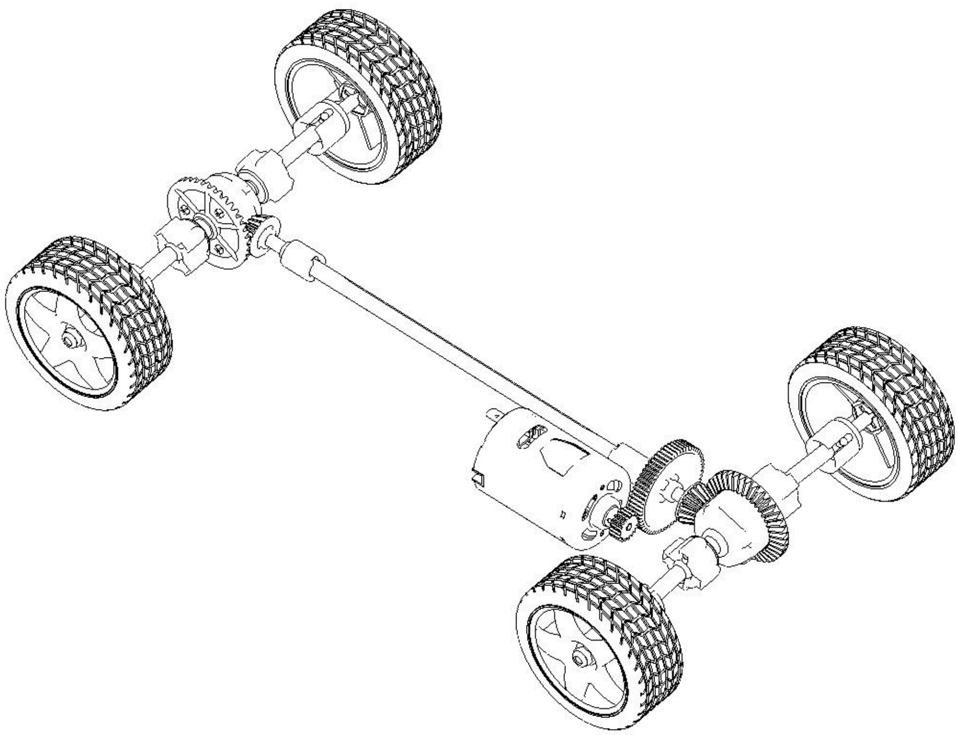
A – Read the transmission's information sheet in order to identify, in the following drawing, the gears that play a role in the reduction of angular velocity between the drive shaft and the drive wheels.

B – Read the form on page 9 to calculate the "i" transmission ratios:

- between the engine and the front driving wheels
- between the engine and the rear driving wheels

C – Do the answers from above seem logical to you? Explain your answer.

A



B

	Between the engine and the front wheels	Between the engine and the rear wheels
"i" transmission ratio		

C

1.3.6

Time required: 10 min

0:50

Top theoretical speed of the car travelling in a straight line.

Questions:

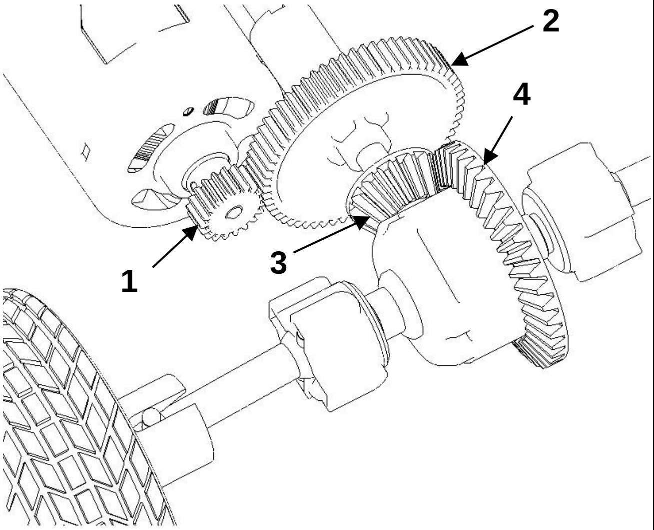
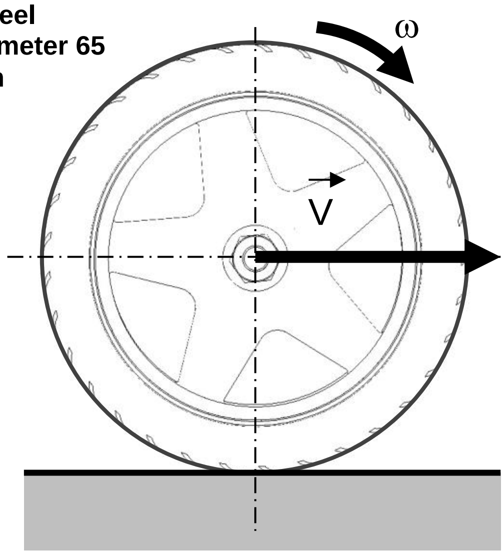
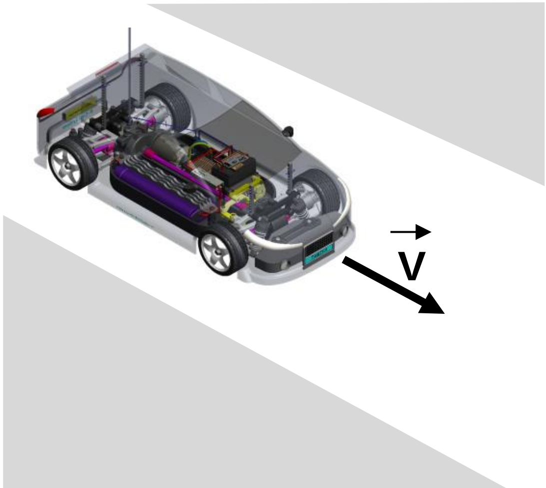
A - Hypothesis: consider a rotational velocity of the drive shaft of 16500 rev/min, which corresponds to the maximum speed without load, i.e. if the engine doesn't encounter any form of resistance to its motion such as friction (which, of course, is not the case in reality).

See the form below … in order to calculate:

- The value of the top theoretical angular speed of the car's driving wheels.
- The corresponding value of the top theoretical speed and the kinetic energy corresponding of the mass of the translatory body (1,5 Kg).

B - In reality, the angular speed of the drive shaft will be inferior to the maximum value, because of phenomena that cause resistance to motion and reduce the speed of the engine. Let us suppose that the reduction of engine speed is of 10%, what would then be the value of the top speed of the car and of the kinetic energy of it translatory mass?

A – All resistance to motion ignored	
N_{engine}	16500 rev/min
ω_{engine} **(rad/s)**	
$\omega_{drive\ wheel}$ **(rad/s)**	
V_{car} **(m/s)**	
$E_{k\ moving\ mass}$ **(J)**	
B – Considering a 10% reduction of engine speed	
V_{car} **(m/s)**	
$E_{k\ moving\ mass}$ **(J)**	

Form		
Gear transmission ratio		**Gear "a":** **Z1 = 19 cogs; Z2 = 61 cogs** **Gear "b":** **Z3 = 15 cogs; Z4 = 39 cogs** **Transmission ratios:** $i_a = \omega 1 / \omega 2 = Z2 / Z1$ $i_b = \omega 3 / \omega 4 = Z4 / Z3$ **with** $\omega 2 = \omega 3$
Forward velocity of the car depending on the angular velocity of the wheel	**Wheel diameter 65 mm** 	$V = \omega \cdot R$ **With:** **V: speed (m/s)** **ω: angular velocity (rad/s)*** **R: wheel radius (m)** *** Conversion:** $\omega = \pi \cdot N / 30$, **N: revolution frequency (rev/min)**
Kinetic energy of a moving mass		**Considering only the mass of the moving body** $E_k = \frac{1}{2} \cdot m \cdot v^2$ **With:** **m: mass of the car (kg)** **v: speed (m/s)**

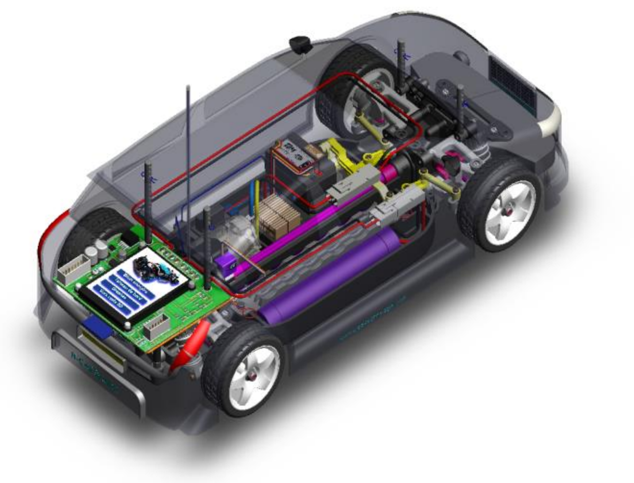
1 – Car Systems

How does the car work in general?
How can we describe its different parts and its possible uses?

1.4
Speed and Consumption of Energy

Full study

Time required: **1h**



Necessary equipment and resources:

Horizon Equipment

- Basic FCAT car with acquisition card

Other equipment:

- Meter stick
- Stopwatch
- String to pull the car manually

Objectives:

We are going to test a basic scale model car, in order to develop experiments that can measure the car's speed and energy consumption as ways to measure its performance.

Motion, speed, energy consumption… How can we measure their values with an on-board system?

Motion:

Moving is changing location or position relative to a fixed reference point. Let's imagine a simple case: we move from one place to another in a straight line. To measure the size of that motion, all one needs is to measure the distance travelled with a ruler, or measuring tape.

However, if we want to fit the vehicle with a measuring device so it can measure its own motion, it is preferable to measure the angle covered by one of the transmission parts, such as a drive wheel or the transmission shaft, and to convert the angle, by manual or programmed calculation, into the corresponding distance travelled. Obviously, the "formula" we will use depends on the device, where it's installed, and on certain features of the transmission type.

Speed:

Speed is the distance travelled in a given time. For example, by travelling 6 metres in 2 seconds, our average speed is 6/2, or 3 metres per second (m/s or $m \cdot s^{-1}$).

Instantaneous speed is the speed of an object at a given moment. One can therefore assume that instantaneous speed is close to the average speed for a very short travel between very close objects.

Energy Consumption:

As it operates, the engine consumes a certain amount of electric power which it converts to mechanical energy. Energy is a value given in Joules, which, in our case, translates in the following manner.

$$E = V \cdot I_{average} \cdot t$$

V : supply voltage (V)
$I_{average}$: average intensity of the current used by the engine (A)
t: travel time (s)

The intensity of the current consumed depends on how much energy the engine requires to overcome the inertia and friction that resist its motion. This value therefore varies according to the resistance load applied to the motor. We can also describe this as instantaneous energy consumption, considering the value of consumed current at a given moment.

Energy can also be described according to the average power produced by the engine, with the following relations:

$$E = P_{average} \cdot t \quad \text{with} \quad P_{average} = I_{average} \cdot V$$

1.4.1

Time required: 15 min

0:05

Tests based on manual traction of the vehicle

See appendix on page 10

Instructions and questions:

Power-up the basic car, fitted with its acquisition card.

Place the car along a measuring tape or a graduated track.

Use a string to pull (manually) the car slowly over a distance of approximately 5 m, while timing the operation.

Then perform a "dashboard"-mode measurement, based on a direct reading on the display of the on-board card, giving the exact travelled distance values and the duration of the operation (remember, distance is an integral value).

Then write down, based on a calculation or on a direct reading of the card's display, the value of the corresponding average speed.

Also indicate, when reading directly the results on the screen, the value of the current consumed by the propulsion engine. Justify this value.

	Based on "manual" measurements with the ruler and the stopwatch	Based on direct readings on the display of the on-board card
Travelled distance (m)	**Value measured:**	
Duration (m/s)	**Timed value:**	
Average speed (m/s)	**Based on calculation:**	
Current consumed by propulsion engine (A)		

1.4.2

Time required: 10 min

0:20

Tests based on radio-controlled propulsion of the vehicle

See appendix on page 10

Instructions:

Repeat the new task twice, by using the remote control to move the car forward over a distance of approximately 10m:

- The first task is to view directly on the display which values have to be reported in the following table
- The second task is to transfer data towards the SD card

	Based on direct readings on the display of the on-board card
Travelled distance (m)	
Duration (s)	
Average speed (m/s)	
Average current consumed by the engine (A)	
Maximum current consumed by the engine (A_{max})	
Average supply voltage to calculate (V)	

1.4.3

Time required: 10 min

0:30

Measuring distance travelled and interpreting data

See appendix on pages 11 and 12

Question:

Read the transmission system's information sheets for the basic car and its acquisition card, and fill in the following table.

Perimeter "P" of a drive wheel	
Distance "d" travelled by the car, for one rotation of the drive wheel	
Number "N_1" of rotations of the drive wheel to travel 1 m	
Transmission ratio "i_b" between the shaft and the wheel, defined on page 11	
Number "N_2" of rotations of the transmission shaft to travel 1 m	
Number "s_2" of signals emitted by the optical sensor, for each meter travelled, knowing that 6 signals are emitted for each rotation of the shaft	
Distance "x" travelled between two signals	
Average speed between two signals, based on "x" and time "t" between two signals	

1.4.4

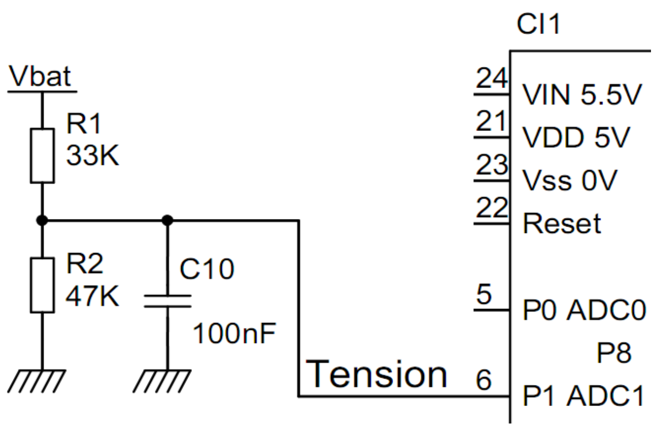
Time required: 10 min

0:40

Voltage measurement and interpretations

The micro-controller of the measurement card is equipped with analog/digital conversion inputs, one of which is used to measure voltage. The converter's resolution is of 10 bits, the scope of the measurements ranges from 0V to 5V.

The battery's voltage Vbat is adapted by a dividing bridge since the voltage of the fully charged battery can exceed 8V. It is slightly filtered by an added condenser.
We now have: Ve = 0.58Vbat



Questions:

A – Considering the suggested assembly, determine the measured voltage Ve based on the Vbat voltage at a constant speed.

B – Based on your answer, what is the maximum Vbat voltage that the microcontroller can measure? (do not take the condenser into account)

A -
B -

1.4.5

Time required: 10 min

0:50

Calculation of power and energy

See appendix on page 13

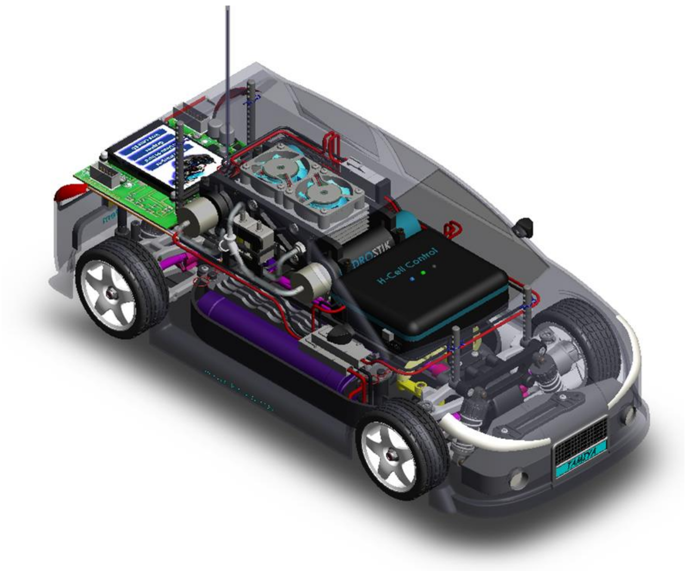
Question:

Fill in the following table using your measurements and calculations.

Average amperage "$I_{average}$" of current consumed by the engine	$I_{average}$ =
Voltage "$V_{average}$" of the battery	$V_{average}$ =
Average power generated by the propulsion engine	$P_{average} = I_{average} \cdot V$ =
Operating time "t" in seconds	t =
Useful energy consumed	$E = P_{average} \cdot t$ =

Appendix

Measuring the operating parameters using the dashboard.



DASHBOARD

Distance covered: 80m
Measurement duration: 28s
Battery voltage: 6.7 - 7.6V

Maximum values
Speed: 25km/h
Useful current: 7A
Useful power: 50W

QUIT

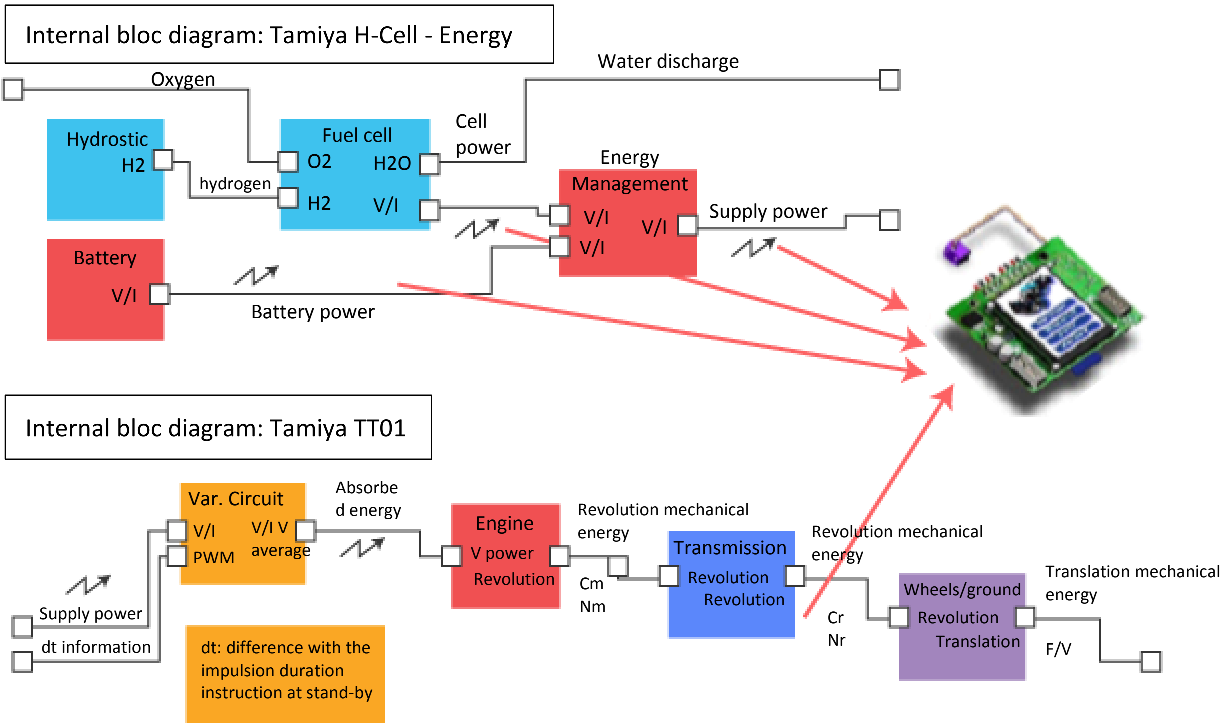
Average values
Speed: 7km/h
Useful current: 0.8A

Consumption values
Fuel cell energy: 152j
Battery energy: 121j
Useful energy: 176j

1 – Turn on the vehicle (button next to the display)
2 – Turn on the hydrogen battery (button on the control casing)
3 – Press the "dashboard" button
4 – Press LAUNCH ACQUISITION to start the measurements
5 – Move the vehicle using the remote control
6 – Press STOP to end the measurements
7 – Record the measured values

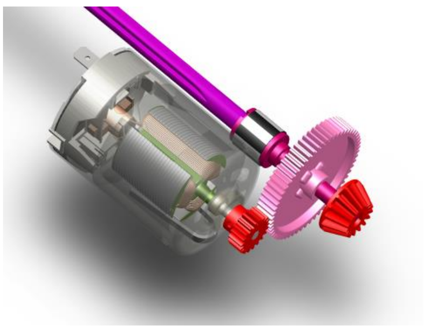
Motion and speed acquisitions on the car

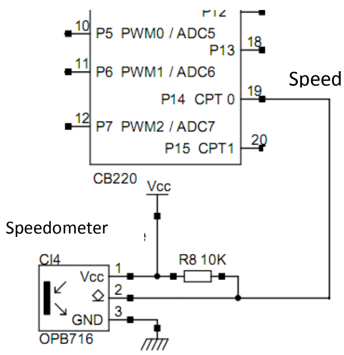
The on-board measurement card enables us to retrieve information about the current, the voltage and the motion of the car. It behaves like a black box that records data as the car moves. The data is recorded onto a memory card to be used later. This information is represented by the three red arrows and is retrieved on the car's propulsion system by sensors and by the logic and analog inputs from the processor. It is recorded by the on-board program and saved as text file on the SD memory.



Based on these measurements and the car and engine's technical features, the vehicle's electrical and mechanical operating parameters can be calculated.

A striped reflector can measure the car's motion. Black and white stripes on the transmission shaft allow an optical sensor to detect how quickly the shaft rotates and the color changes



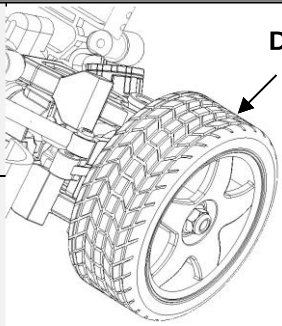


The sensor used here is a reflection detector. An infrared light is emitted by a diode and is then reflected by the white stripes and not the black ones. The signal transmitted to the sensor is sent to a counting input on the microcontroller, and the counter increases at each change of state from white to black or black to white. Each incremental change of the counter corresponds to a travelled distance that remains to be calculated. The coder has 6 white stripes and 6 black stripes.

Relation between the wheel's rotation angle and the distance travelled.

$x = \theta \bullet r$

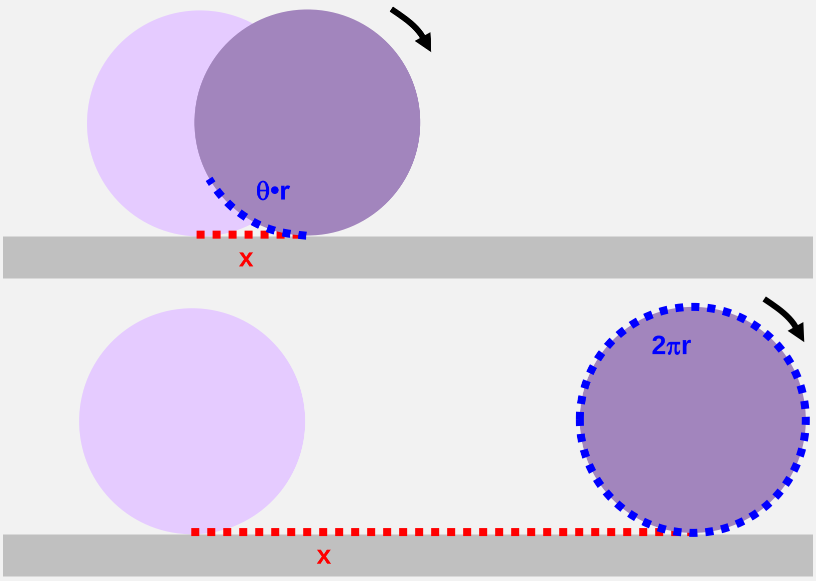
- x: travelled distance (m)
- θ: rotation angle of the wheel (rad)
- R: wheel radius (m)



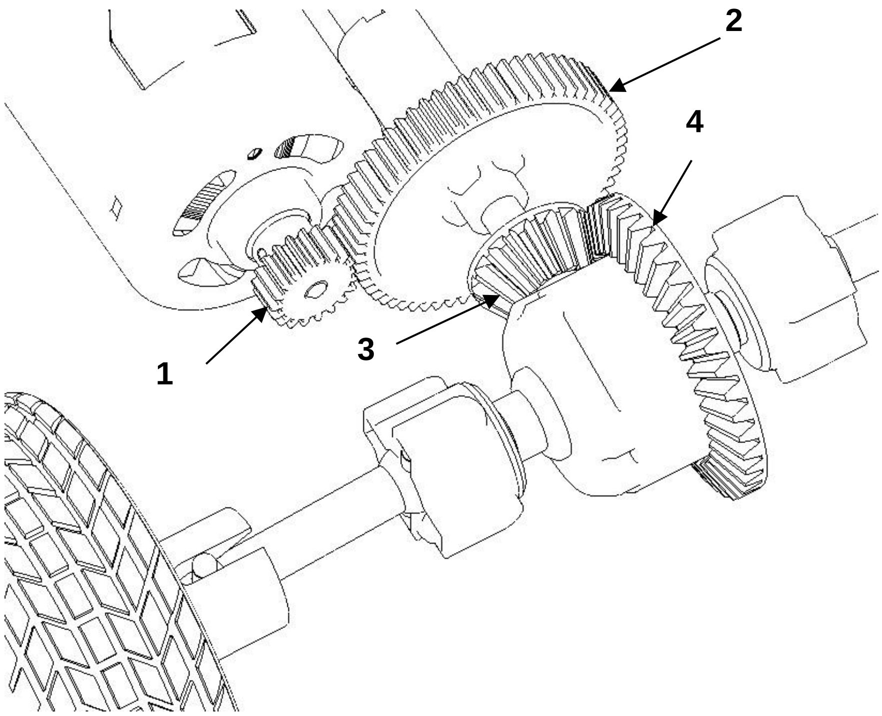
For a full rotation of the wheel: $\theta = 2\pi$ rad,

therefore $x = 2\pi r$

(which corresponds to the perimeter of the wheel)



Transmission ratios



Gear "a":

Z1 = 19 cogs; Z2 = 61 cogs

Gear "b":

Z3 = 15 cogs; Z4 = 39 cogs

Transmission ratios:

i_a = N1 / N2 = Z2 / Z1

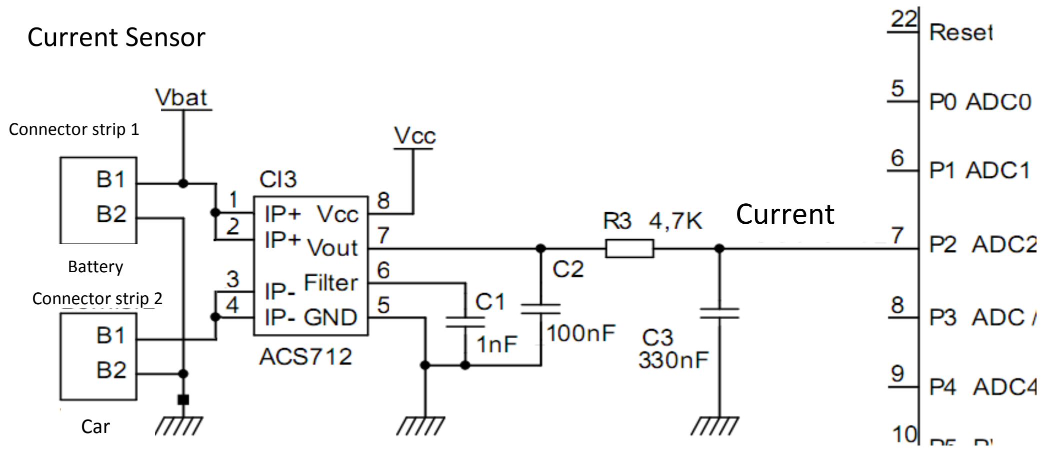
i_b = N3 / N4 = Z4 / Z3

with N3 = N4

Global ratio: $i_g = i_a \cdot i_b$

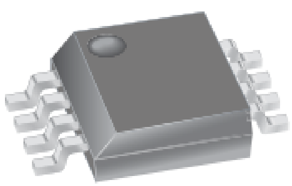
Battery voltage and current acquisitions

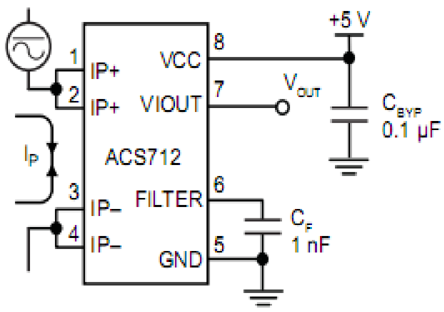
The card's microcontroller is fitted with analog/digital conversion inputs. The analog input is used to measure current. Current released by the battery travels through an integrated circuit that captures the Hall effect current. The output voltage of the sensor is filtered to reduce sudden variations of the chopper and is then measured by the microcontroller.



The current emitted by the + connector of the battery travels through pins 1 and 2 towards pins 3 and 4.

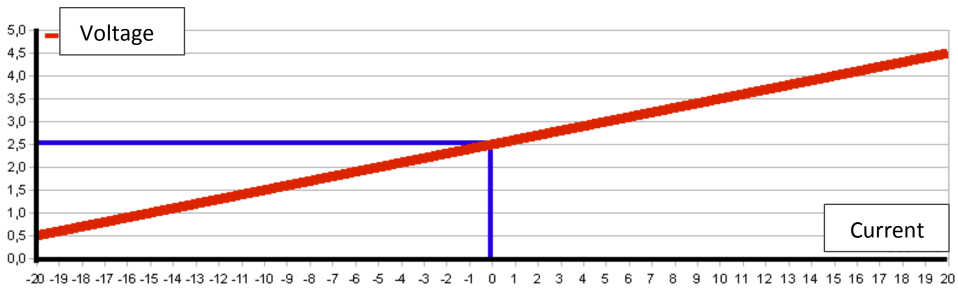
Extract from the documents:





The resolution of the circuit is of 100mv/A. The measurement range goes from -20A to +20A. Here, only positive currents are measured.

The evolution of voltage based on current is as follows:



Calculation of power and energy

The Joule is the standard unit of energy, equal to the work produced by applying a force of one Newton over one meter, or to the work provided by an electrical current of one Ampere travelling through one Ohm of resistance during one second. Its symbol is J.
Energy can also be expressed in kilowatt-hours, which are commonly used in the construction business: 1 kwh = 3,600,000 J

The Joule is also the product of power and time, but here it is given in Watts and seconds (E = P•t), where E is in Joules, P is in Watts and t is in seconds, or E in kWh, P in kW, and t in hours

In everyday life, and approximately:

- 1 joule:
  - is enough energy to lift one apple (100 grams) by one meter (close to the earth's surface)
  - is enough energy to increase the temperature of one gram (1 litre) of air by one degree Celsius.
- 1000 joules:
  - the quantity of heat that a resting person lets out in 10 seconds;
  - the energy required by a child (30 kg) to climb a set of stairs (a little over three meters).
- 1 mega joule (one million joules):
  - fifteen minutes of heating with a 1000 W heater.

It's difficult to measure energy directly. Generally, we measure other physical dimensions and use them to calculate energy. For example:

In electricity… for direct current provided by a battery, the product of the current in amperes and the voltage in volts provides the power in watts: **P = I•V**

In mechanics… in the case of linear travel, the product of the force in Newton and of speed in meters/second provides the power in watts: **P = F•v**

Glossary

Hall effect sensor: A device that measures magnetic fields. Since a current generates a magnetic field, the intensity of the field can be used to measure the intensity of electric currents. They are sometimes used as position detectors: in brushless-type electric engines, for instance, they detect the variation of the magnetic field at the passage of one of the rotor's poles. The Hall effect was discovered in 1879 by Edwin Herbert Hall.

Chopper: The chopper, or direct-direct converter, is an electronic power device that uses several controlled switches to change the value of the average voltage from a source of direct voltage with a high yield. The chopping is carried out at high frequency without influencing the operation of the powered system (engine for example).

Microcontroller: a microcontroller is an integrated circuit that includes all the essential components of a computer: processor, memory (RAM for data, read-only memory for programs), peripheral units and input-output interfaces. Microcontrollers feature a higher integration level, lower electric consumption, reduced operating speed (from a few megahertz to a few hundred megahertz) and are cheaper compared with versatile microprocessors used in home computers.

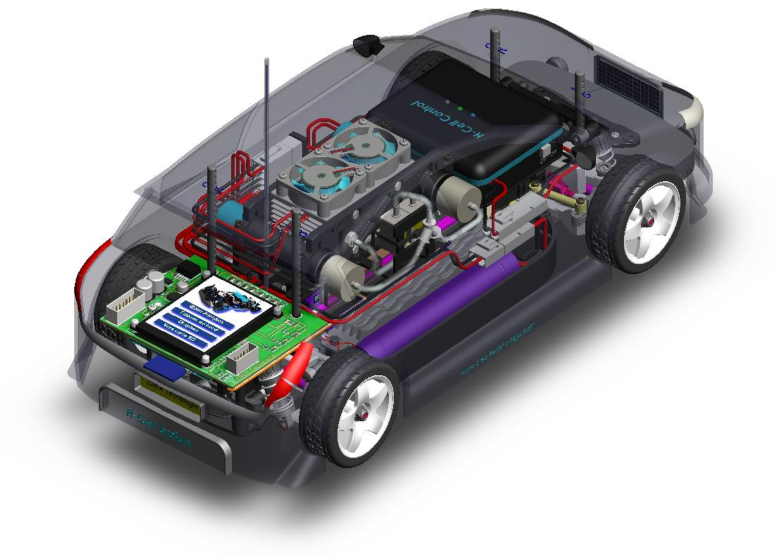
1 – Car Systems

**How does the car work in general?
How can we describe its different parts
and its possible uses?**

**1.5
Measuring
Changes in
Electrical Energy**

Full study

Time required: **1h**



Necessary equipment and resources:

Horizon Equipment:

- FCAT car (with full Hydrostiks) with acquisitions' card
- Battery charger
- Partially depleted battery
- Fully-charged battery

Objectives:

We are now going to examine how electricity behaves within a hybrid system, using a series of measurements retrieved from the acquisitions' card.

An on-board energy reserve...
to provide enough power while
still protecting the environment

Consuming power, using one or several on-board power reserves

In the previous activity, we examined what happened to the car's energy consumption based on how it moved on a track.

The power used is taken from an actual energy reserve, fitted on the scale model. Its capacity limits the total amount available onboard the vehicle, and therefore how long it can run.

A Problem of Range:

Here, the battery represents the only power available on the basic model. It gives us approximately 15 minutes of running time, which seems rather small and, to be honest, insufficient. How can this be increased? Either by reducing the amount of power used (not always easy), or by increasing the capacity of the power reserve. Let's examine the second solution:

- By increasing the capacity of the battery? More batteries means more toxic chemicals inside batteries, and that would go against what we're trying to do to protect the environment. It's more suitable, in the long term, to try to use storage means that are more respectful of the environment.

- By replacing the battery with another type of reserve? With a greater capacity for reduced size, and therefore a more environmentally-friendly solution? By using hydrogen for example? Yes, but we'll soon realise that this power reserve alone isn't sufficient to meet our needs when the motor needs more power: up steep hills for example, or on loose terrain, or during a sharp acceleration phase.

Why not then combine these two technologies?... electrochemical battery + hydrogen cartridges?... using a "hybrid" operating mode? The idea seems enticing, given that we cannot, for the moment, do without electric batteries. In theory, it would enable us to reach, in the H-Cell-equipped modal, 50 minutes of running time!

Managing Energy Flows:

This new concept depends on the optimal management of electrical power coming from the battery and the fuel cell in order to increase the vehicle's range.

For this purpose, we will examine the maker's solution, by looking at some of the measurements taken on the hybrid system.

1.5.1

Time required: 5 min

0:05

Battery alone

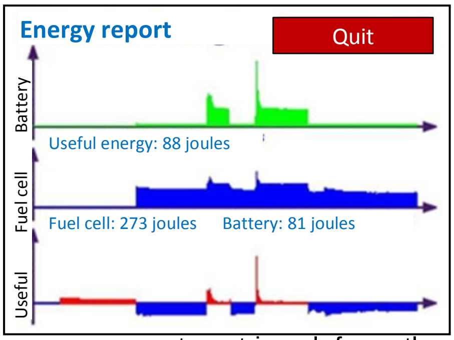
Questions:

Examine the battery's technical data, and write down its voltage and capacity in the following table.

Voltage (V)	
Capacity (mAh)	

1.5.2

Time required: 15 min



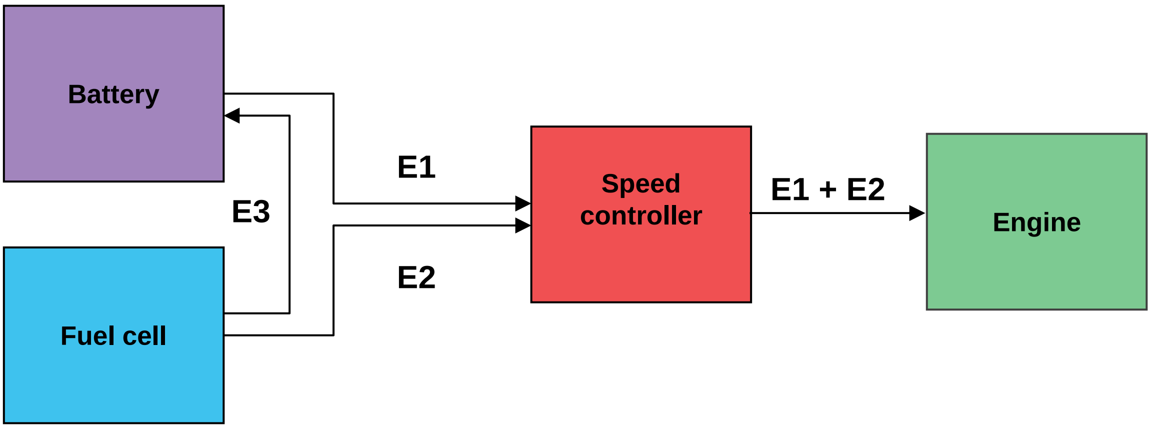
General instructions on reading the acquisitions' card

0:10

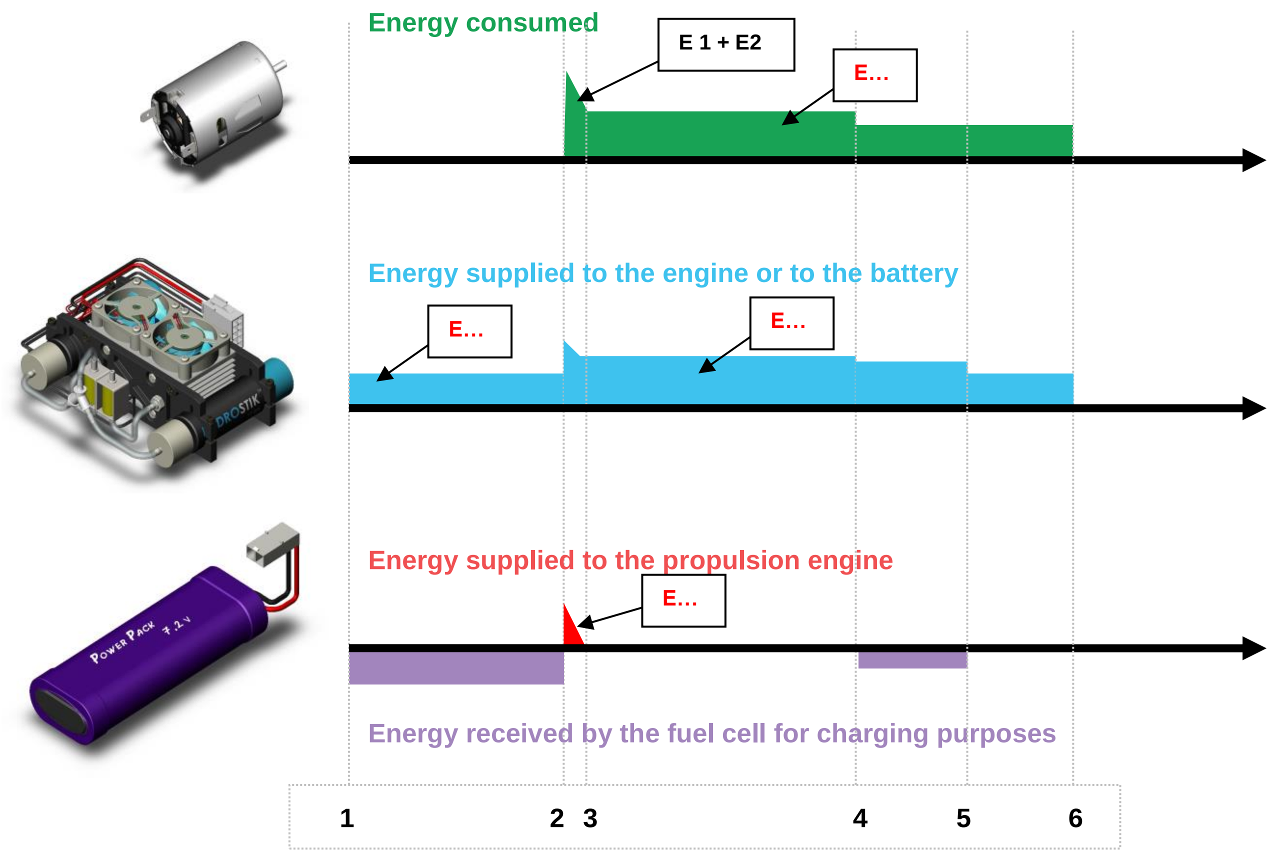
Question:

On the next page, examine the various measurements and energy amounts retrieved from the acquisitions' card.

On that page, indicate (in the boxes) the energy flows such as are shown in the graph below, and then fill in the table.



E1: Electric energy provided by the battery to power the propulsion system
E2: Electric energy provided by the fuel cell to power the propulsion system
E3: Electric energy provided by the fuel cell to charge the battery



E1: Electric energy provided by the battery to power the propulsion system
E1: Electric energy provided by the fuel cell to power the propulsion system
E3: Electric energy provided by the fuel cell to charge the battery

	from 1 to 2	from 2 to 3	from 3 to 4	from 4 to 5	from 5 to 6	beyond 6
The engine	**is stopped**	**starts**	**runs at constant speed**	**runs at reduced speed**		**is stopped**
The fuel cell						
The battery						

1.5.3

Time required: 05 min

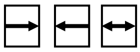
0:25

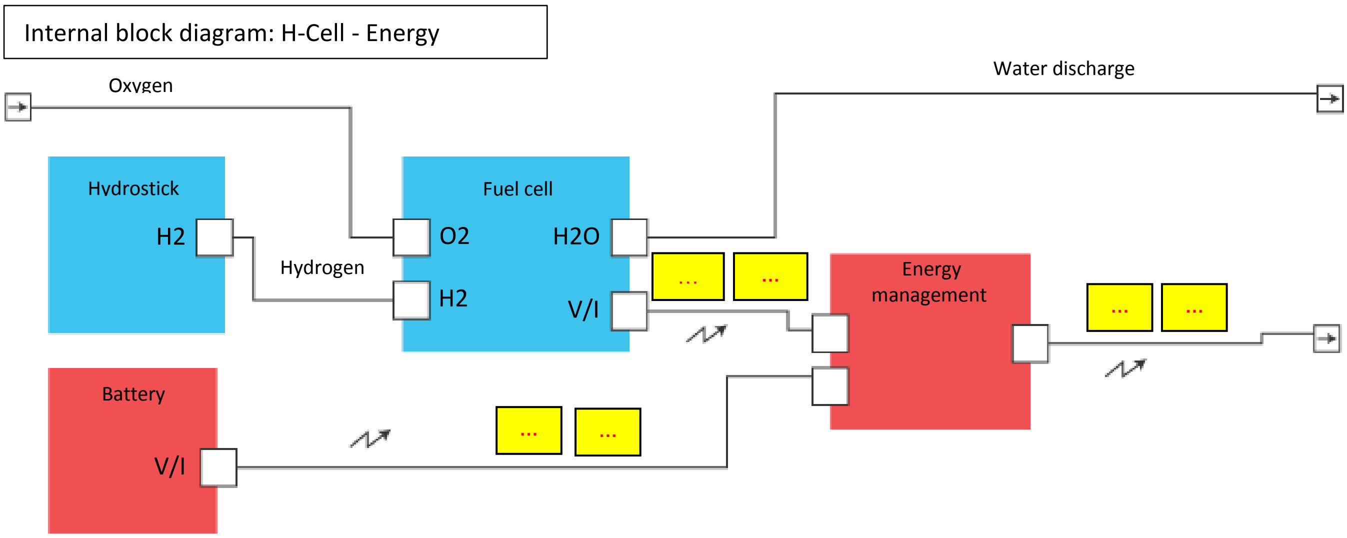
Interpretation of the SysML diagram

Question:

Fill in the following diagram, by providing the energy flows mentioned on the previous page (report them in the yellow boxes), and indicate on the ports the direction of the energy flow (you may use double arrows as shown below).

Images to copy/paste on the diagram according to the direction of the flow:



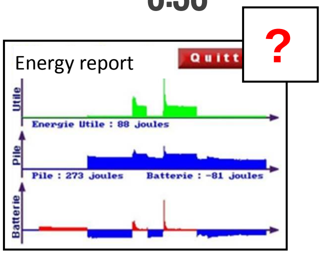


E1 or **E3**: Electric energy supplied or received by the battery
E2: Electric energy provided by the fuel cell to power the propulsion system
E1 + **E2**: Electric energy provided by the fuel cell (and/or) the battery to power the car

1.5.4

Time required: 15 min

0:30



Fuel cell + partially depleted battery

Energy measurements on the acquisitions' card

Question:

Test the car to see how it functions with a powered hybrid system, when the battery is partially depleted. Report your observations below with a schematic and relevant comments

1.5.5

Time required: 15 min

0:45

Fuel cell + fully charged battery

Question:

Now equip the car with a fully charged battery and repeat the previous tests.