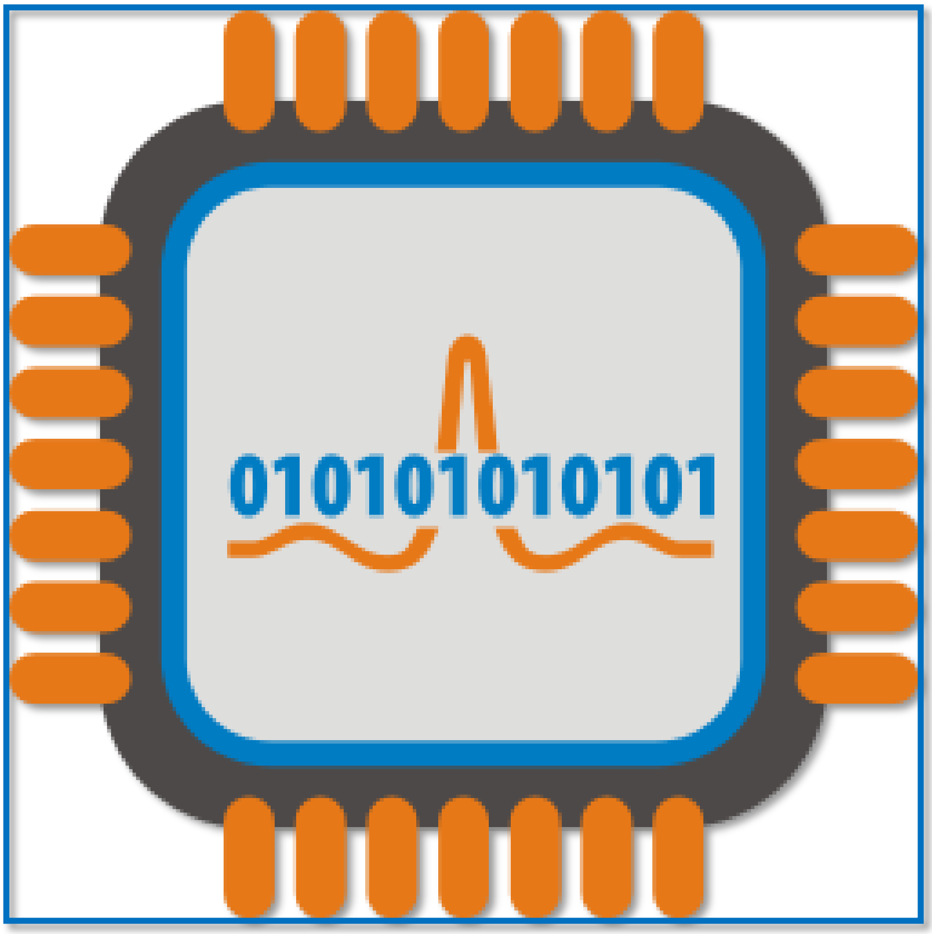
ANALOGUE AND DIGITAL ELECTRONICS

STUDENT'S WORKBOOK



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NILE Norwich, April of 2011

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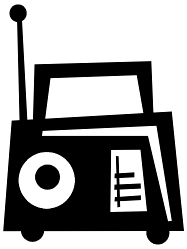
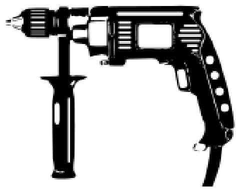
1 INTRODUCTION TO ELECTRONICS.

1.1 Electricity and electronics.

1 Do you know the names of these objects?

2 Complete the definitions of electronic and electrical technology.

Electrical	*technology*	*energy*	*Electronics*

____________ is the branch of science and ____________ that deals with electrical circuits applied to information and signal processing.

____________ technology deals with the generation, distribution, switching, storage and conversion of electrical ____________.

3 Classify the objects from the first activity as electrical or electronic.

Electrical	
Electronic	

When you finish, check the answers with your partner. Don't look at their answer. You can use these models.

Is a light bulb an electronic or electrical device?

I think it is an electric device because it converts electric energy.

I think it is an electronic device because it processes information.

1.2 Past, present and future of electronics.

4 Match these pictures with their names and definitions.

Transistors

A miniaturized electronic circuit manufactured on a substrate of semiconductor material.

Integrated circuits

A device used to amplify and switch electrical signals by controlling the movement of electrons in a low-pressure tube.

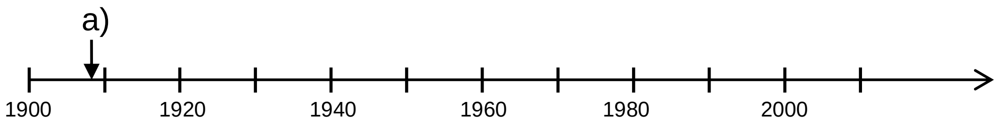
Vacuum tubes

A solid semiconductor device used to amplify and switch electronic signals.

5 Find out what year these things happened by reading the text below.

a) _ _ _ _ Invention of the vacuum tube.	d) _ _ _ _ Start of radio broadcasting.
b) _ _ _ _ Invention of the transistor.	e) _ _ _ _ Start of black and white television.
c) _ _ _ _ First microchip.	f) _ _ _ _ First mobile phone in your family.

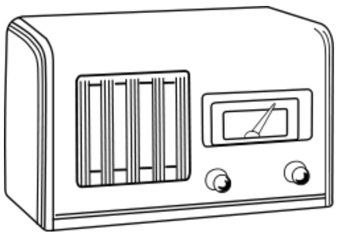
Place them on the timeline.



<u>Summary of the history of electronics</u>

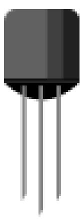
Electronics originated from electrical science at the beginning of the 20th century.

In 1883, Thomas Alva Edison discovered the thermionic effect. Electrons flow from one metal conductor to another through a vacuum. In 1904, T. A. Fleming built the first **vacuum tubes.** These devices can amplify electrical signals.

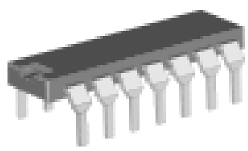


The first applications of electron tubes were in radio communications. Vacuum tubes made weak audio signals from radio waves stronger. **Radio broadcasting** grew in the 1920s.

Development of the television benefited from many improvements made to radar during World War II. Television became widely available in 1947.



After the war, electron tubes were used to develop the first computers, but they were impractical because of the sizes of the electronic components. In 1947, the **transistor** was invented by a team of engineers from Bell Laboratories. The transistor works like the vacuum tube, but it is smaller, consumes less power, is much more reliable, and is cheaper.



Around 1960, the first **integrated circuits** were made. Integrated circuits are also called microchips, or IC. The typical IC consists of resistors, capacitors, and transistors packed on a single piece of silicon. Microcomputers, microwave ovens and mobile phones are examples of devices made possible by integrated circuits.

In 1971, INTEL manufactured the first microprocessor with 2300 transistors. By 2009, the number of transistors in some microchips was more than 10 billion.

At the moment, scientists are working on molecular electronics, optical and quantum computing. These and other emerging technologies will bring developments that we cannot imagine.

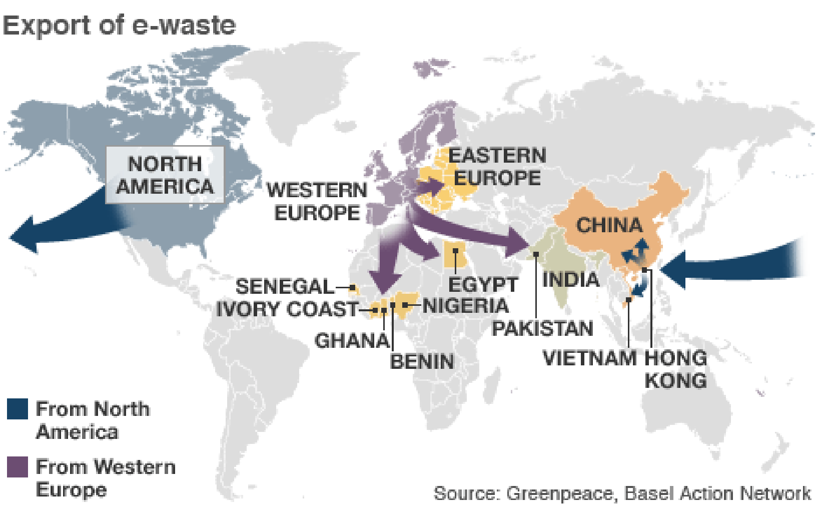
6 Fill in the gaps with data from the text above.

Date	Invention	Applications
1904		
	Transistor	
1960		

Be ready to answer following this model:

The microprocessor was invented in 1971. Its applications are ….

7 Look at these pictures and listen to the text. Then answer the questions below.



a) What is e-waste? *E-waste is …*

b) Where does most e-waste go? *Most e-waste is exported to …*

c) Do you think e-waste is toxic? .... *because electronic products contain heavy metals such as lead and mercury and hazardous chemicals.*

d) E-waste will be a bigger problem in the future because more and more people use more and more electronic devices and change them more often. Talk to your partner and try to find a solution to the e-waste problem.
   - *Governments should …*
   - *We all should …*
   - *Electronic products should …*

1.3 From analogue to digital electronic systems.

You already know that the function of an electronic system is to process information. Any electronic device can be thought of as three linked parts – input, process, output.

In electronics we use a block diagram to represent the parts of a system.

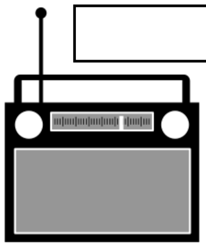
INPUT ⇨ PROCESS ⇨ OUTPUT

1. The **input** part takes in energy of some form and produces an electrical signal.
2. The **process** part modifies or does some calculations with the electrical signal.
3. The **output** part produces a new energy output from the processed electrical signal.

8 Label the objects by using the language bank below and identify the input and output block for each one.

Megaphone

Input		Process		Output
MICROPHONE	⇨	ELECTRONICS	⇨	LOUDSPEAKER
It converts sound to electrical signals.		It processes electrical signals.		It converts electrical signals to sound.



	⇨	ELECTRONICS	⇨	
________________		It processes electrical signals.		________________

	⇨	ELECTRONICS	⇨	
________________		It processes electrical signals.		________________

	⇨	ELECTRONICS	⇨	
________________		It processes electrical signals.		________________

- Digital thermometer
-Loudspeaker
- Aerial
- Senses changes in temperature and produces an electrical signal
- Takes in electromagnetic waves and produces an electric signal
- Calculator
- It transforms electrical signals to sound
- Display screen
- Push-buttons that generate electric signals
- keypad
- Temperature display
- It gives a readout of temperature
- It converts electrical signals to visible
- Temperature sensor
- Radio

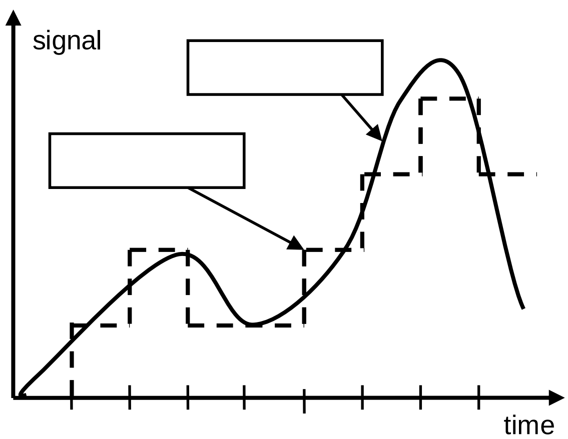
Check answers with your partner and be ready to answer following this pattern.

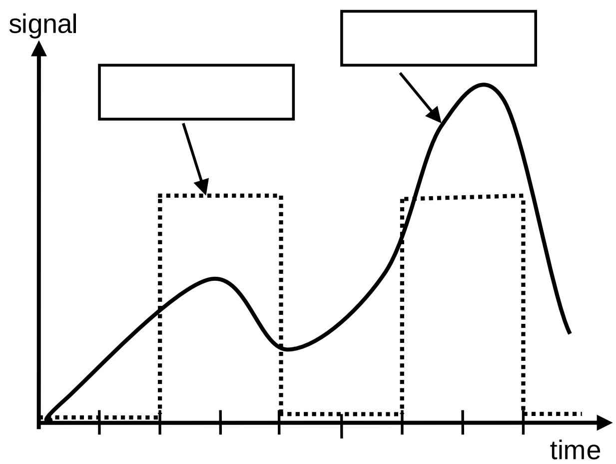
Object number 1 is a megaphone.
The microphone converts sound to electrical signal. This signal is processed by the electronics and then the loudspeaker converts it to sound.

Electronic signals can be analogue or digital.

- An **ANALOGUE** signal continually changes and can have any value in a given range.
- A **DIGITAL** signal can only have certain, discrete values.
- **DIGITAL BINARY** signals are a subgroup of digital signals that can have only two states, ON (1) or OFF (0). There are no values in between.

9 Label these signals as analogue, digital or digital binary.



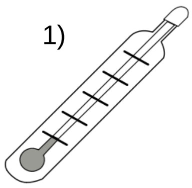


Match the sentences with arrows.

The dashed signal is	digital binary	because it has any value.
The continuous signal is	analogue	because it has only two values
The dotted signal is	digital	because it has only certain values.

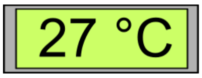
10 We can think of objects as analogue or digital. Can you write the names of the following objects in the diagram?

1)



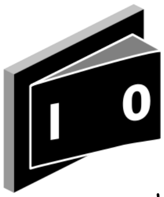
th______et__

2)

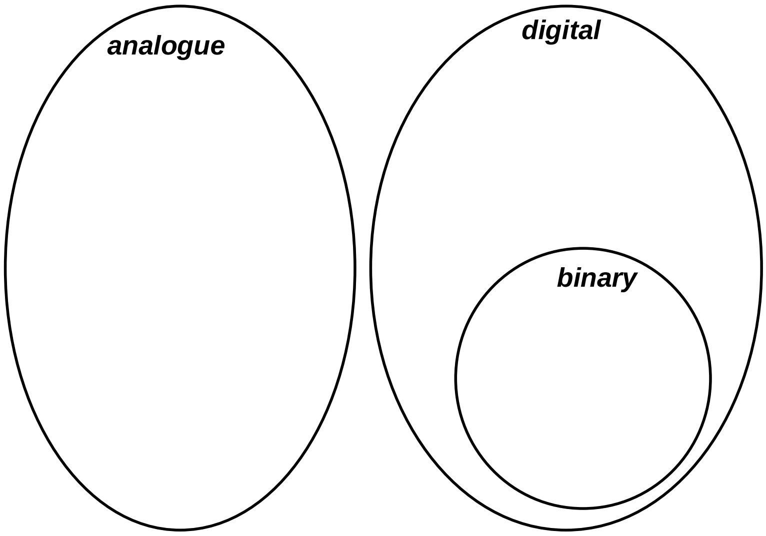


d_____ay

3)



s_____h



Check the answers with your partner.

What do you call object 1?
Is it analogue or digital? Why?

It is a....
I think it is........... because .....

11 The following text about noise has some blanks. Your teacher will give you a text with half of the gaps filled in. Your partner will have the other half.

1. Copy them into your workbook.
2. Now dictate to each other to complete the text.
3. Agree on a heading for the text.

HEADING:____

Signals in nature are analogue. For example____________________________(a). It is analogue because it can be any value.

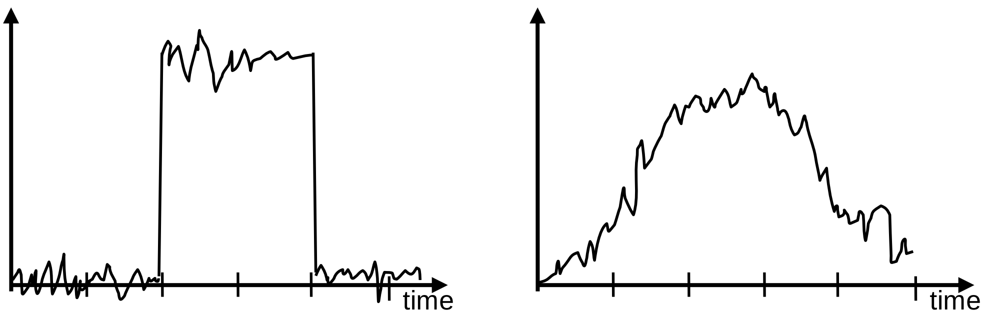
______________________________________(b):

- *They can be converted to numbers and easily________________________(a).*
- *They are easy to store and to compress using mathematical algorithms.*
- *Noise ________________________(b) as much as to analogue signals.*

When data is transmitted, processed or stored a certain amount of ***NOISE*** ________
____________________(a).

With an analogue signal, noise cannot be ___________________________ (b). We have distortion. In a digital signal, noise will not matter, as any signal close enough to a particular value will be interpreted as that value.

Draw the original signal in colour.



Which one is more difficult to rebuild? *The .... signal is easier to reproduce because it can have only ....values.*

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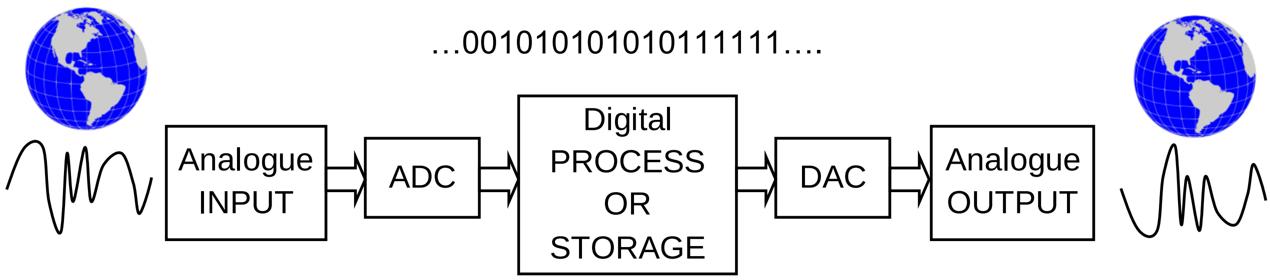
12 Listen to the text about the analogue-digital conversion process. Fill in the gaps and answer the final question.

Analogue signals are processed by analogue __________ and digital signals are processed by __________ circuits. In between, we can use these electronic circuits to _____________ from analogue to digital and vice versa.

- *ADC: analogue-to-digital converters*
- *DAC: digital-to-analogue converters*



For example, we can get ___________ with a microphone and analogue electronics. Then an ADC converts this signal to digital __________. This data can be __________ and stored in a digital format, such as ________.

Home electronics used to be analogue but nowadays everything is mainly digital. So, we have digital TV, digital photography, digital ____________, etc.

Circle the right answer:

a) DAC stands for analogue-digital-conversion.
b) Modern electronics is mostly digital.
c) To play mp3 music we have to use a DAC.
d) Sound is a digital signal.

13 Decide if these sentences are true or false. If they are false change them so that they are true.

T / F A cassette tape is the digital evolution of a CD (compact disc).

....

T / F DVB (digital video broadcasting) has no noise because it is an analogue signal.

....

T / F Analogue photography can be easily modified, compressed and transmitted.

....

T / F An ADC converts digital signals to analogue.

....

T / F Digital electronic systems are older than analogue systems.

....

T / F All digital signals are binary signals.

....

Self assessment: In the next unit you are going to learn more about analogue electronic circuits. Before you move on make sure that you can answer yes to these questions.

QUESTION	No	More or less	Yes
Can I order the main developments in electronics and say what decade they happened?			
Do I know what problems e-waste can cause and how to avoid them?			
Can I draw a block diagram for a basic electronic system?			
Can I give examples of analogue, digital and binary signals?			
Can I compare analogue and digital systems?			

2 ANALOGUE ELECTRONICS.

2.1 Resistors.

Resistors are components which resist the flow of electricity through a circuit for a given voltage. A resistor implements electrical resistance.

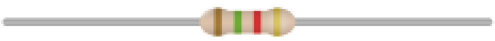


Image of a resistor

Symbol of a resistor

1a Remember the main electrical magnitudes and find the unit for each one.

Magnitude	*Unit*
Voltage (V)	
Electric current (I)	
Power (P)	
Electric resistance (Ω)	

Watt (W)   Volts (V)   Ohms (Ω)   Ampere (A)

1b **OHM'S LAW** connects resistance, voltage and current in an electrical circuit. There are many ways to express this relationship: with text, with formula and graphically.

a) Formula for finding the voltage across a resistor for a given current. $\boxed{V = I \cdot R}$

b) Formula for finding the current through a resistor for a given voltage. $\boxed{I = \frac{V}{R}}$

Which formula represents these formulations of Ohm's law better, a) or b)?

[___] The voltage (V) across a resistor is proportional to the current (I) passing through it, where the constant of proportionality is the resistance (R).

[___] When a voltage V is applied across the terminals of a resistor, a current I will flow through the resistor in direct proportion to that voltage.

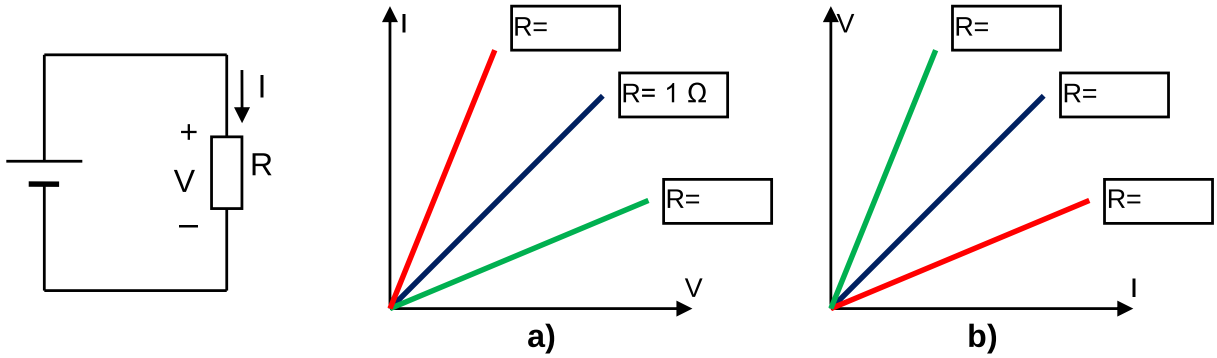
[___] Voltage across a resistor equals the current through it multiplied by the resistance.

[___] Current through a resistor equals the voltage across it divided by the resistance.

1c Choose the right answer or answers.

a) The higher the resistance, the lower the current.
b) The higher the resistance, the higher the current.
c) The lower the resistance, the higher the current.
d) The lower the resistance, the lower the current.

1d In this circuit, R can be 0.5 Ω, 1 Ω or 2 Ω. Identify which resistance corresponds to each graph.



Construct a sentence that makes sense for graph a) and one for graph b).

a) The ....

b) The ....

The lower The higher	the resistance,	the lower the higher	the current the voltage	for a given	voltage. current.

The Ω is too small for many resistors. Then we use the **MULTIPLES** kilo (k) and mega (M). Sometimes, to avoid reading errors, the letters R,k and M substitute the decimal point. Look at the examples.

4k7 = 4.7 kΩ = 4,700 Ω
5M6 = 5.6 MΩ = 5,600,000 Ω
3R3 = 3.3 Ω

2a Give the value in Ω for the following resistors.

a) 6k8 =
b) 1M2 =
c) 47R =
d) 5R6 =

Write the answers like this:

5M6: five point six mega-ohms are five million six hundred thousand Ω.

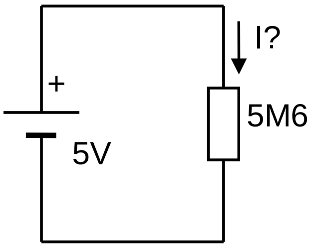
a) 6k8: ....

b) 1M2: ....

c) 47R: ....

d) 5R6: ....

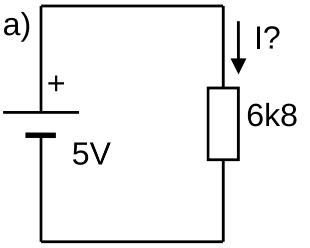
2b Now apply Ohm's law to calculate the current through the resistors as in the example. When you finish, check the answers with your partner without reading their workbook.



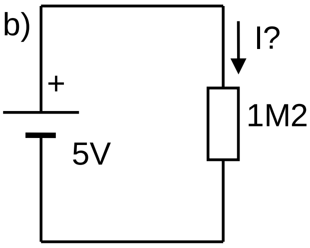
$$I = \frac{V}{R} = \frac{5}{5{,}600{,}000} = 0.00000089\ A = 0.89\ \mu A$$

Remember: 0.001 A = 1 mA and 0.000001 A = 1µA

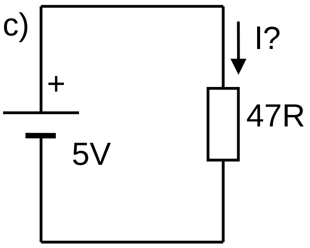
a)



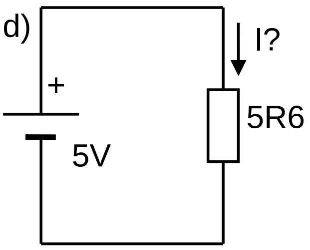
b)



c)



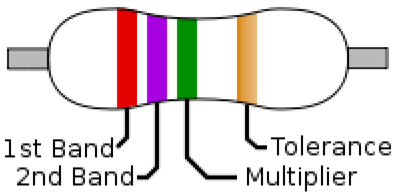
d)



What result did you get for part a) ?

3a Fill in the blanks looking at the table below.

A lot of resistors have coloured rings on them instead of numbers. Each colour stands for a different unit: black is zero, brown is _____, red is two; orange is three; yellow is ______; green is five; _____ is six; violet is seven; grey is ______; white is nine, as you can see in the table below. The first band is for tens and the second band for units. The third band is the multiplier.



Example: red / violet / green stands for 2 / 7 / 00000, that is 2700000 Ω or 2.7 MΩ.

1st colour band		2nd colour band		Multiplier		Tolerance	
Black	0	Black	0	Silver	divide by 0.01	Silver	10%
Brown	1	Brown	1	Gold	divide by 0.1	Gold	5%
Red	2	Red	2	Black	multiply by 1	Red	2%
Orange	3	Orange	3	Brown	multiply by 10		
Yellow	4	Yellow	4	Red	multiply by 100		
Green	5	Green	5	Orange	multiply by 1,000		
Blue	6	Blue	6	Yellow	multiply by 10,000		
Violet	7	Violet	7	Green	multiply by 100,000		
Grey	8	Grey	8	Blue	multiply by 1,000,000		
White	9	White	9				

3b Obtain the value of these resistors:

a) Brown / green / red:
b) Orange / orange / brown:
c) Green / grey / yellow:
d) Yellow /violet / orange:

Express the previous values with M or k if possible. For example 27000 Ω = 27 kΩ

3c Manufacturers of the resistors cannot guarantee the exact value. The fourth band expresses the **TOLERANCE** in %. With the tolerance we can calculate the minimum and maximum real values for the four resistors below as in the example:

Red /violet / orange //silver
R =27000 Ω ±10%

10% of 27000 = 27000·10/100=2700
R = 27000 Ω ± 2700 Ω
Minimum value =27000-270=26730 Ω
Maximum value = 27000+270=27270

Colours	Value	Tol. %	Tol.	Minimum	Maximum
Red /violet / orange //silver	27000 Ω	10%	2700	26730 Ω	27270 Ω
Brown / green / red // silver					
Orange / orange / brown // gold					
Green / grey / yellow // silver					
Yellow /violet / orange // gold					

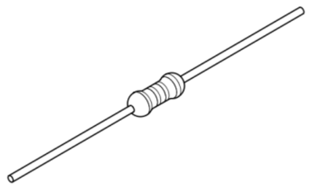
3d Work with your partner in turns. Choose 1 resistor from the pool and write down its colours. Then you have to tell your partner the colours and he has to find out the value.

1kΩ 680 kΩ 330 kΩ
1.8 MΩ 2200 Ω
1.5 kΩ 270 Ω
1.2 kΩ 8.2 kΩ
120Ω 270 kΩ 18 Ω
3.3 MΩ
390 Ω 820 Ω
4700 kΩ 5.6 kΩ 47 kΩ

- My resistor is brown, black, red.
- Yes, it is. You are right…

- Is it 1000 Ω?
- My resistor is …

3e Your teacher will give you one real resistor. Note down the colours, calculate its value and write the text to describe your resistor to the class.



The first band colour of my resistor is……

The quoted value is ……………………..

The tolerance is…

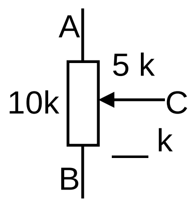
The minimum…

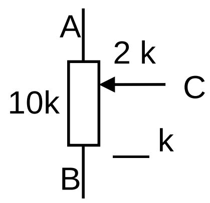
TYPES OF RESISTORS.

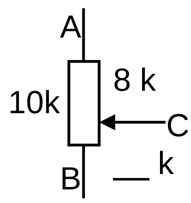
You already know about **fixed resistors**. They are the most common type of resistor.

Variable resistors are also known as potentiometers. They are used to act on a circuit, for example to adjust sensitivity or to change gain. They have 3 legs. The resistance between the two outside legs (R_{AB}) is fixed. By moving the middle leg or cursor, we adjust the resistance between the middle leg and the outside legs. The three values are linked like this: $R_{AB} = R_{AC} + R_{CB}$.

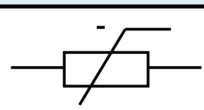
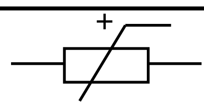
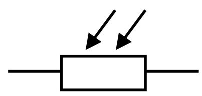
4a Can you get the values for R_{CB} in these 10 kΩ potentiometers?







Special resistors change resistance as a result of a change in other magnitudes. They are used in sensing circuits.

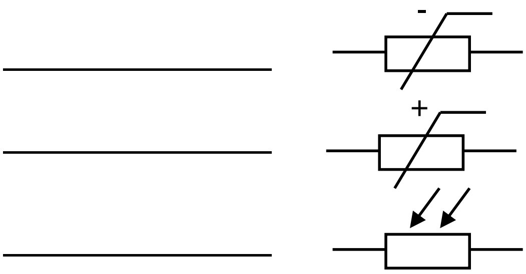
Name	Depending on	Coefficient	Symbol
NTC Thermistors	Temperature	Negative	
PTC Thermistors	Temperature	Positive	
Light-dependent resistors (LDRs)	Light	Negative	

4b Explain how the special resistor works as in the model:

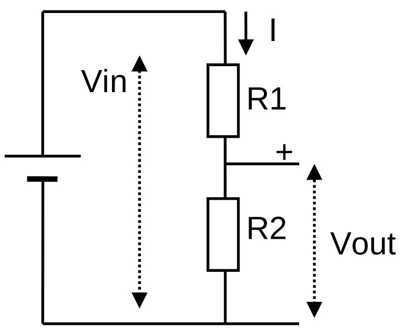
- NTC thermistors' resistance changes according to the temperature. As temperature goes up, the resistance goes down. They are used in temperature-sensing circuits.
- PTC ....
  ....
- LDRs ....
  ....

4c Complete the visual organizer.

Resistors
- __________ resistors.
- Variable or ______________
- ________ _________
  - ________________
  - ________________
  - ________________



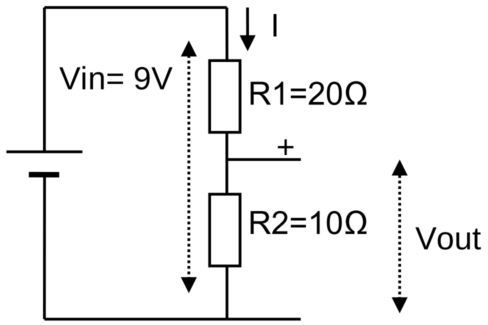
POTENTIAL or VOLTAGE DIVIDERS are used for dividing up the voltage, so that parts of a circuit receive only the voltage they require. They usually consist of two resistors connected in series across a power supply.



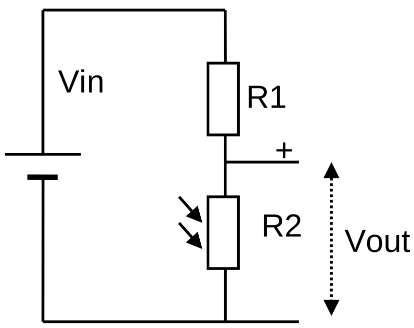
$$Vout = Vin \cdot \frac{R2}{R1 + R2}$$

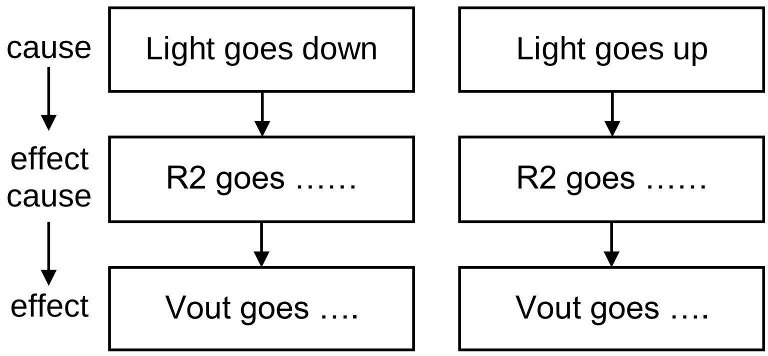
Potential dividers are used, for example, with LDRs in circuits which detect changes in light.

5a Calculate Vout by applying the formula of a voltage divider.



5b When one of the resistors is a special resistor the circuit is a sensor. Predict how light changes will affect Vout.

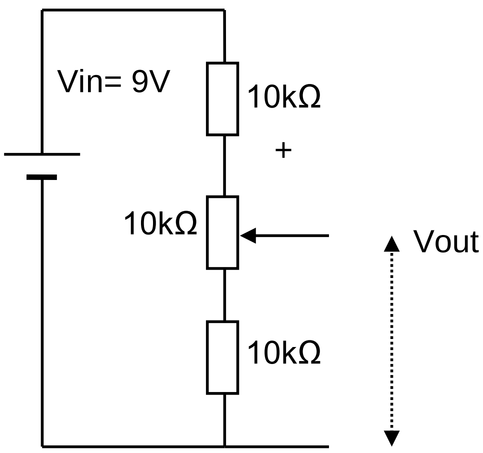




Prepare to answer questions like

- What is the effect of light going down?
- What is the cause of Vout going up?

5c Calculate the minimum and maximum values of Vout that we can get by adjusting the potentiometer.

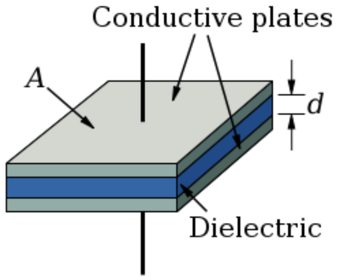


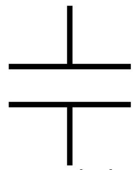
2.2 Capacitors.

6a Listen and fill the gaps in this text about capacitors.

A capacitor is a discrete component which can store an electrical charge. The larger the ______________ the more _______ it can store.

Capacitors are used in ______ circuits, to filter __________ and as _________ devices.





Symbol

6b The unit of capacitance is the Farad. As this is a large amount, these submultiples are used:

micro-Farad (µF)	nano-Farad (nF)	pico-Farad (pF)
1µF =10^{-6} F 1µF = 0.000001 F	1nF = 10^{-9} F 1nF = 0.000000001 F	1p F = 10^{-12} F 1p F = 0.000000000001 F
1 F= 1,000,000 µF = 1,000,000,000 nF = 1,000,000,000,000 pF		

Convert these values to Farads as in the example. Check answers with your partner.

Example: 33 nF = *0.000000033 F = 33·10^{-9} F*

a) 100 pF =

b) 10 µF =

c) 0.1 µF =

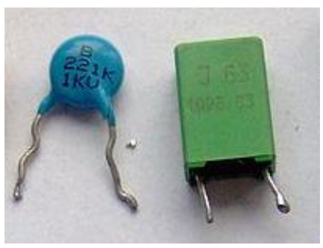
d) 68 nF =

6c Read the text and then answer the questions below.

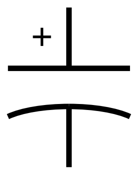
The small capacitance capacitors are made of polyester (nF) and ceramic (pF).

For large capacity values (µF) electrolytic capacitors are used. These are polarised and marked with the maximum voltage.

Be careful not to connect electrolytic capacitors the wrong way or across a higher voltage.



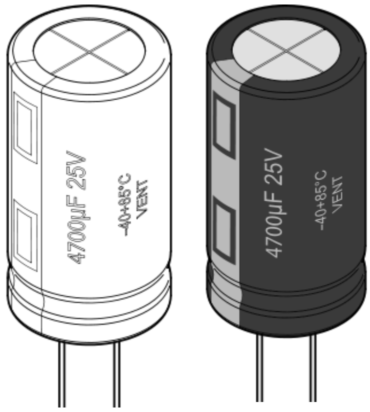
Ceramic and plastic capacitors



Polarised capacitor symbol

What kind of capacitor is this?

It's an e........................ c...............................



Describe its characteristics?

Its value ....

....Volts.

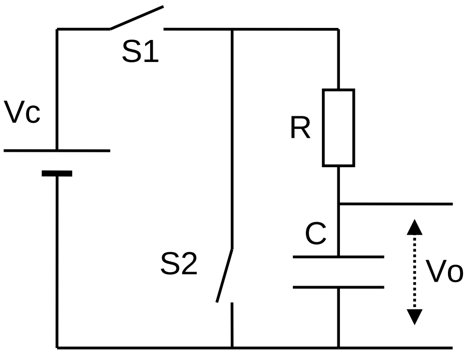
It can work between ....

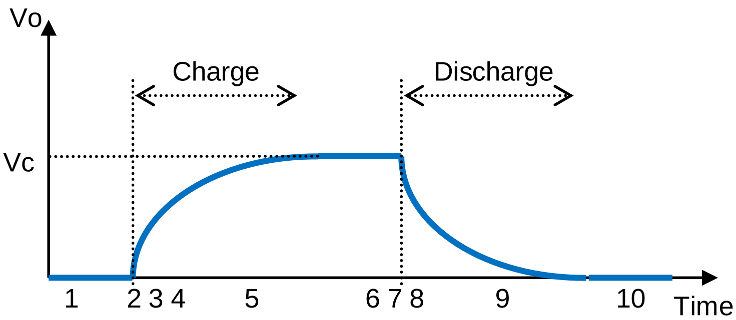
Discuss with your partner what will happen if we use them in a 50V circuit?

I think it ....

because...

7a Usually we connect a capacitor in series with a resistor for timing purposes. The flow of current through a resistor into the capacitor charges it until it reaches the same voltage than the power supply. Analyse the diagrams and try to sequence the text with your partner putting order numbers in the empty cells.



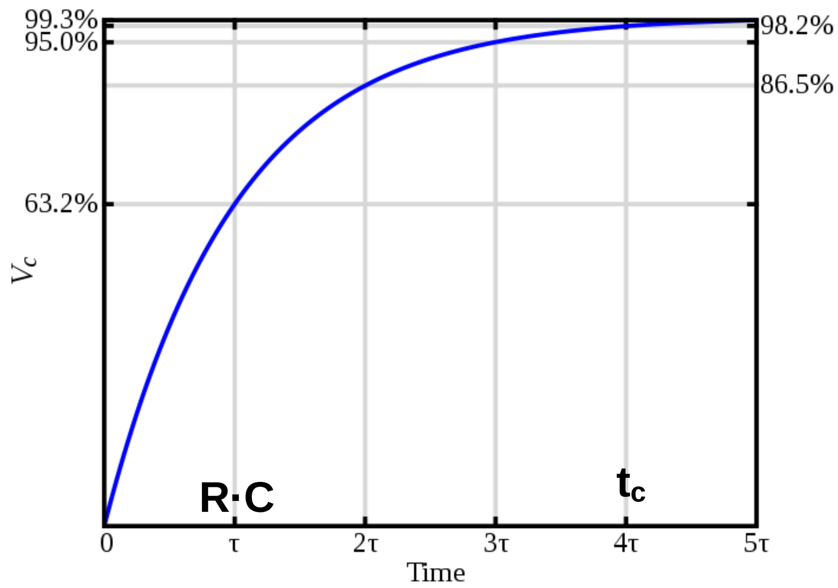


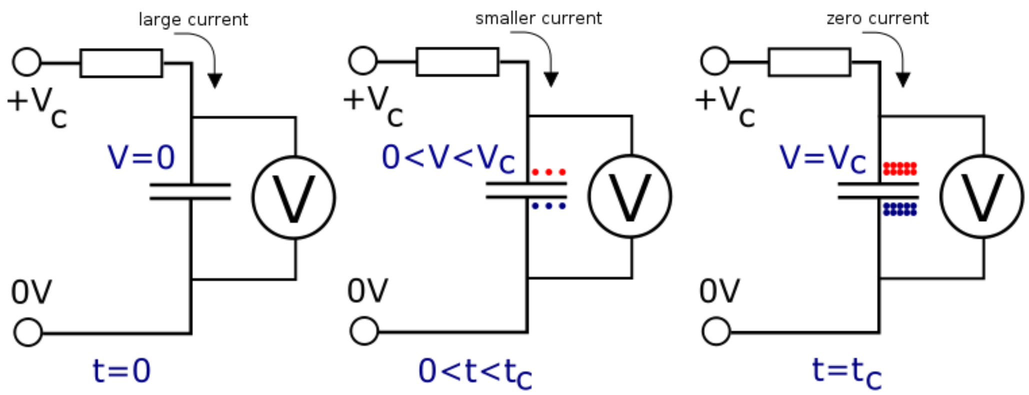
A	The capacitor starts discharging sharply through R.	
B	S1 is switched off and S2 is switched on.	
C	At the beginning switch 1 and 2 are off.	1
D	The capacitor starts charging fast through R.	
E	The capacitor is fully discharged.	
F	S1 is switched on.	
G	Vo rises slowly as it approximates Vc.	
H	The capacitor is fully charged at Vc.	
I	The voltage across the capacitor rises sharply.	
J	Vo decreases slowly as it approaches 0V.	

7b The time it takes to charge a capacitor depends on a time constant called tau. Tau depends on the resistor and the capacitor. The total charging time (**t_c**) is approximately 4 times this time constant.

$\tau = R \cdot C$

$t_c = 4\,\tau$





a) What % of the final voltage does the capacitor reach after τ? And after 4τ?

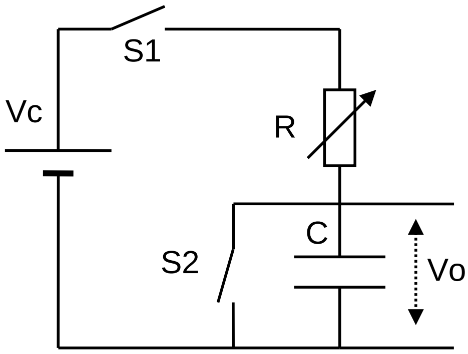
b) Calculate the time constant for R=100 kΩ and C=100μF.

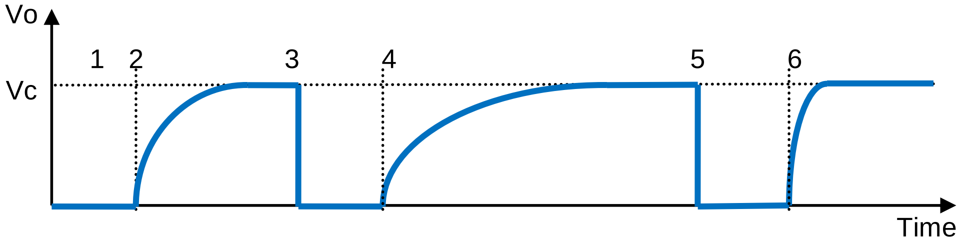
c) What happens to the charging time if we halve the value of the resistor?

d) What happens to the charging time if we double the value of the capacitor?

7c This circuit is similar to that of activity 7a. Note that this time R is adjustable. Explain what actions the following graph describes. Pay special attention to what happens between 3 and 4, and between 5 and 6.

When you finish discuss your results with your partner.



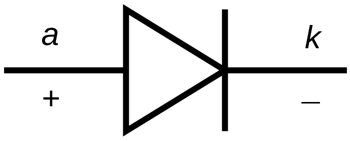


At the beginning, S1 and S2 are off...

At instant 2, switch 1 is...

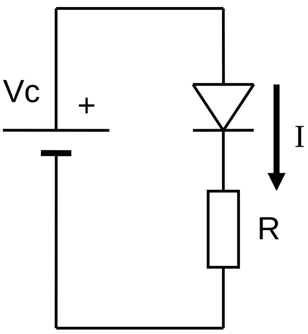
2.3 Diodes.

Semiconductors are materials that conduct electricity under certain conditions. Silicon is the most used to make electronic components.

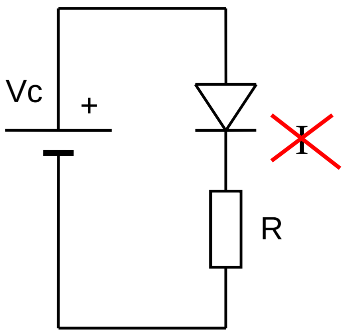


symbol

Forward bias



Reverse bias



A diode is a semiconductor device that allows current to flow in one direction. It can be used for protection, to block signals, to change AC to DC, etc.

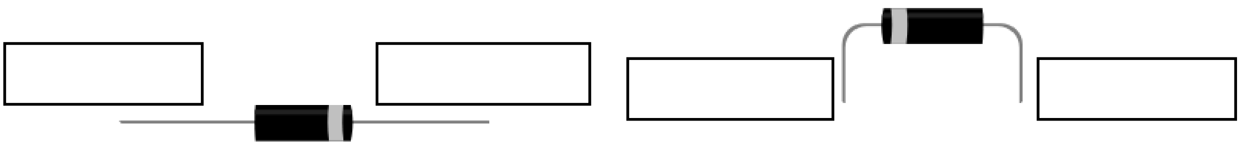
The two leads are called anode (a or +) and cathode (k or -).

8a Look at the diagrams above and fill in the blanks.

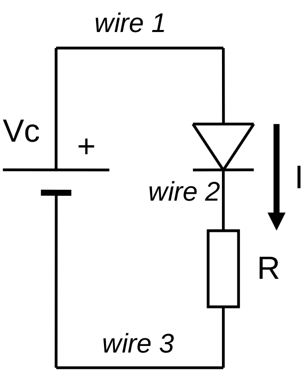
The current can only flow from ______ to _______. This direction is called ______ bias.

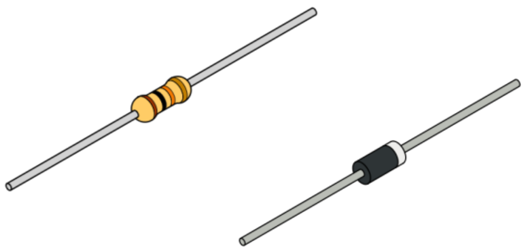
The current cannot flow from _______ to ______. This direction is called _______ bias.

8b The cathode is identified by a band on its body. Label the leads of these diodes as anode or cathode.



8c Draw wires to connect this diode in direct biasing as seen in the circuit diagram.

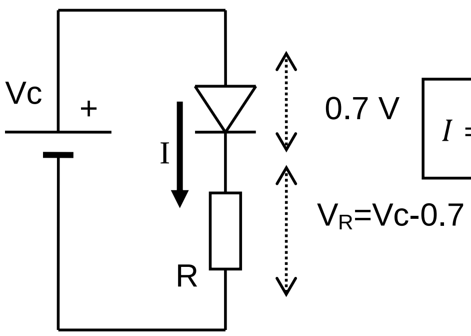




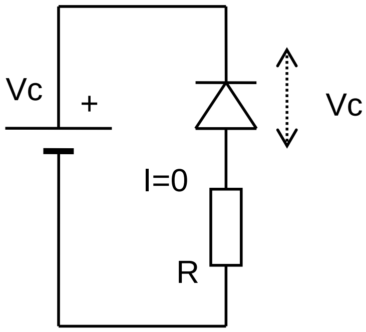
Explain to your partner how you have connected the wires:

The first wire goes from positive lead of the battery to ....

The voltage needed to operate the diode in forward bias is about 0.7 V. Here you can see how to calculate the current in forward bias.

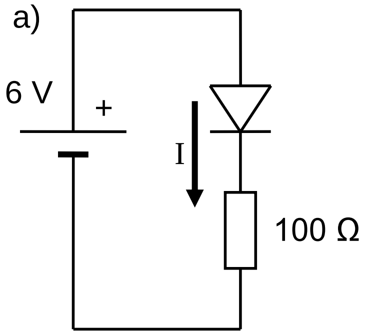


$$\boxed{I = \frac{V_R}{R} = \frac{Vc - 0.7}{R}}$$

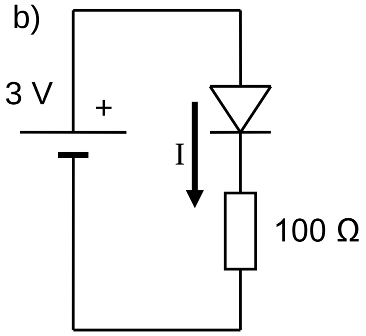


9 Calculate the current (I) in these 3 circuits.

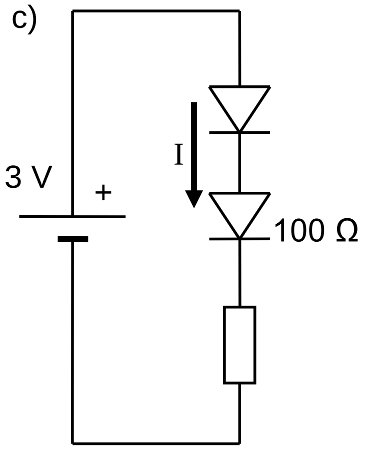
a)



b)



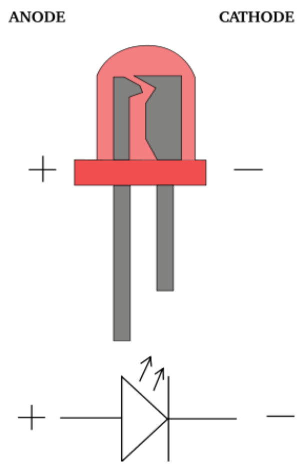
c)

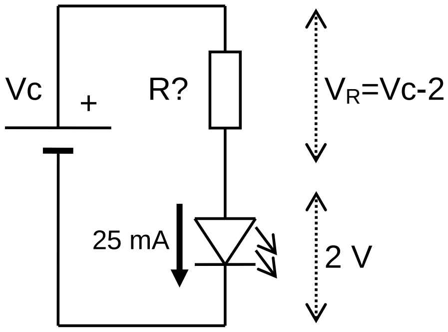


Light-emitting diodes or **LEDs** are made from different semiconductor materials that give off light when connected in forward biasing.

The forward bias voltage can be between 1.6 V and 3.5 V depending on the colour (2 V for red colour).

Usually an LED is connected in series with a resistor to limit the current between 20 mA and 30 mA. More current would fuse it. You can see the usual circuit and the equations below to calculate the current or the resistor value.



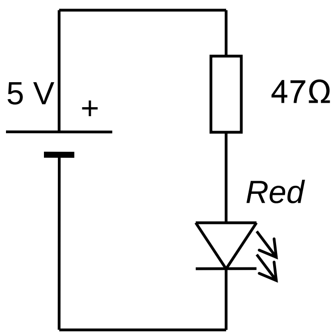


$$I = \frac{V_R}{R} = \frac{Vc - 2}{R}$$

$$R = \frac{V_R}{I} = \frac{Vc - 2}{I}$$

10 Is the LED in the circuit safe?...................... Why (not)?.......................................

....

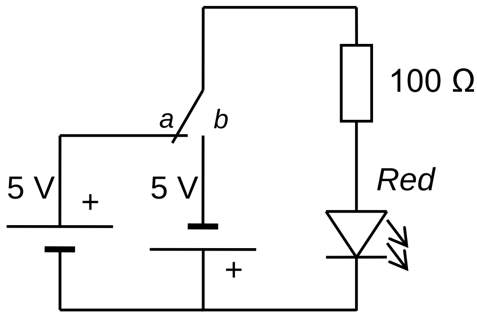


Calculate the resistor value to set the current to 30 mA.

Calculate a new resistor value to set the current to 20 mA.

11a Look at the circuit and answer these questions. You can ask your partner.

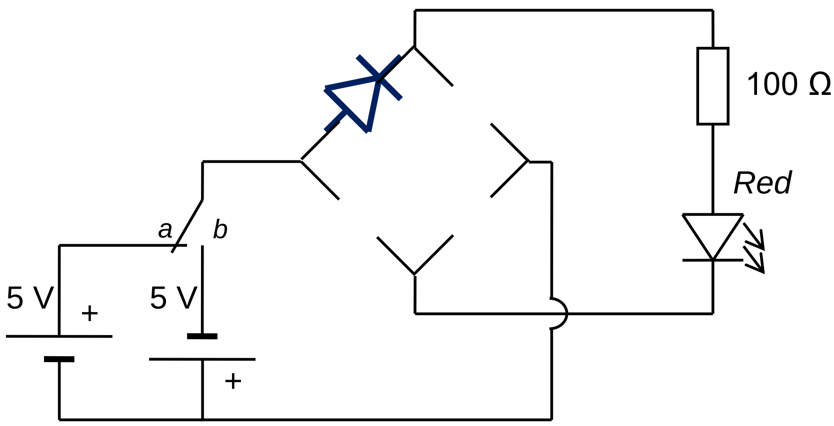
- Will the LED glow when the switch is at position “a” ?
- .... it w........... because it is ....biased.
- What will the voltage across the resistor be?
- It will be..
- Will the LED glow with the switch at position “b” ?
- .... it w........... because it is ....biased.
- What will the voltage across the resistor be?
- It will be..



11b The following circuit is a bridge rectifier. It is widely used to convert AC into DC.

a) Place 3 more diodes in the circuit so that the LED glows in both positions of the switch. Draw in blue the two diodes that conduct when the switch is at position *a*. Draw in red the ones that conduct in position *b*.

b) What will the current through the resistor be?



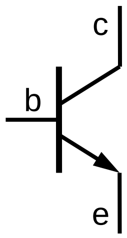
2.4 Transistors.

12a Listen to the text and fill in the blanks.

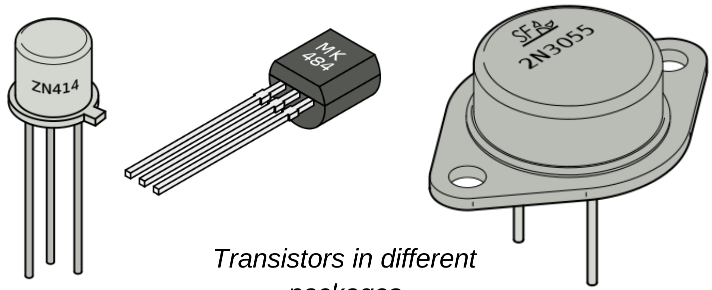
A transistor is a semiconductor device used to ________ and ________ electronic signals. We will focus on the common NPN bi-polar type of transistors.

It has terminals for connection to an external circuit. The three leads are:

- *The _________ (b), which is the lead responsible for activating the transistor.*
- *The collector (c), which is the __________ lead*
- *The emitter (e), which is the negative _________.*



NPN bi-polar transistor symbol

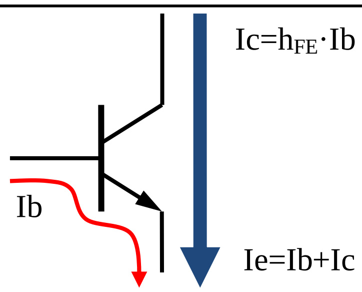


Transistors in different packages

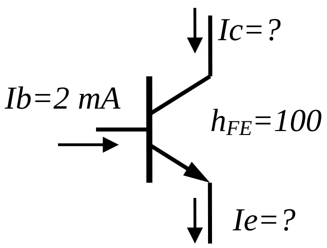
When a small _________ flows through the base-emitter circuit, a much larger current flows through the collector-emitter ________.

$$\boxed{Ic = h_{FE} \cdot Ib}$$

The gain (h_{FE}) is the amount by which the transistor amplifies current. Usual values are around 100.



12b Calculate the Ib and Ie for the given Ib and h_{FE} as in the example.

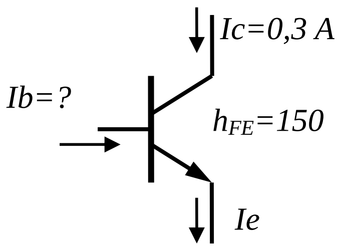


$$\boxed{\begin{array}{c} \mathbf{Ic} = h_{FE} \cdot Ib = 100 \cdot 2mA = \mathbf{200\ mA = 0.2\ A} \\ \mathbf{Ie} = Ib + Ic = 2 + 200 = \mathbf{202\ mA = 0.202\ A} \end{array}}$$

a) Ib=0.1 mA; h_{FE}=80

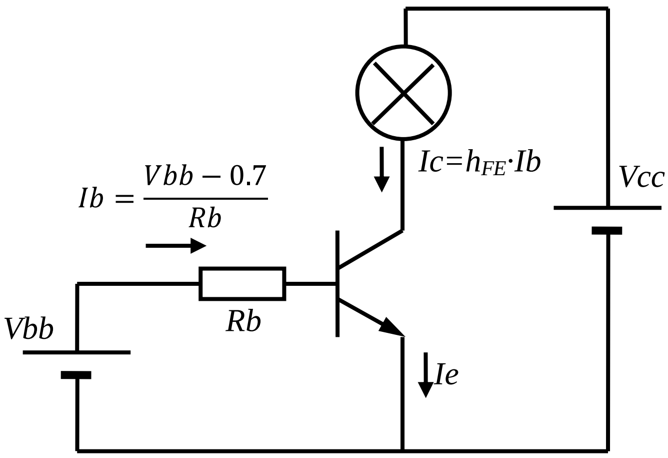
b) Ib=12 mA; h_{FE}=120

c) Can you calculate the Ib that we need to get Ic=0,3A if h_{FE}=150?



12c As with diodes, a voltage of 0.7V is necessary across the base-emitter to activate the transistor. In this circuit you can see the formula to calculate the current into the base. Then you can calculate the current into the collector.

Find out Ib and Ic for these values:
a) Vbb=3V; Rb=100Ω; h_{FE}=100



13a Discuss with your partner and find two ways to make the light bulb glow brighter in the last circuit.

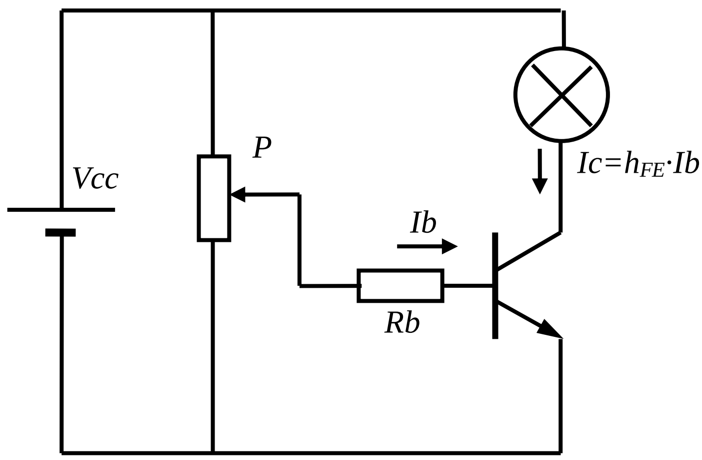
If we increase/decrease Vbb If collector current goes up/down If base current goes up/down	then	base current will go up/down. the light bulb will glow brighter /dimmer. collector current goes much higher/lower.

a) One way to make the light bulb glow brighter is to increase .... because then ....

b) Another way to do it is ....
....

13b In this circuit the transistor works as a **CURRENT AMPLIFIER**.

Match sentence beginnings with endings.



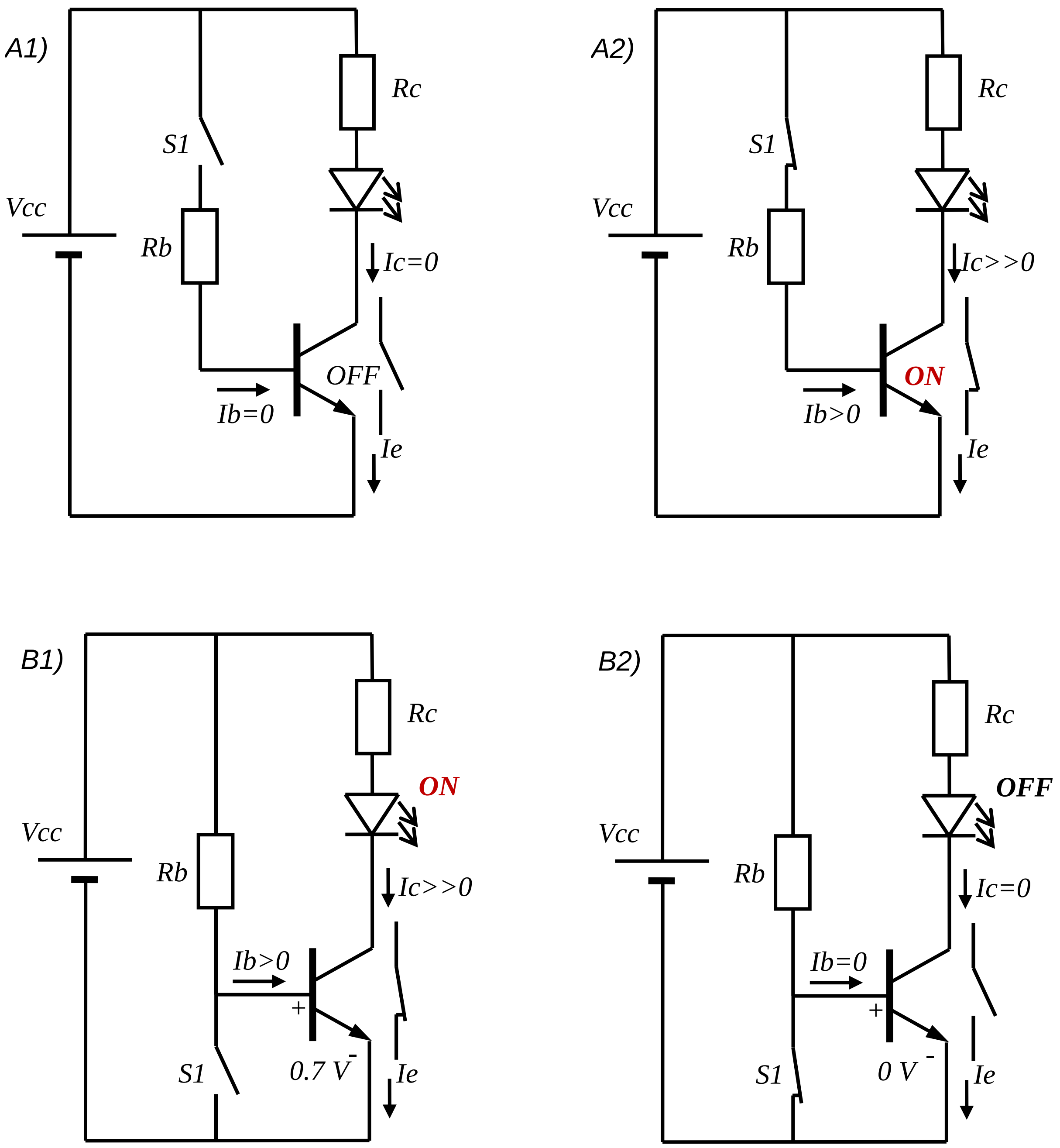
1. The potentiometer.............................
2. Moving the cursor up is like..............
3. To make the light bulb glow dimmer..
4. The collector current is controlled......

a) you have to move the cursor down.
b) by the potentiometer.
c) works as a potential divider.
d) making Vbb higher in exercise 12a.

In many cases we don't need to control the collector current in a continuous analogue way. We just want 2 states. It works as a **DIGITAL SWITCH** controlled by the base current:

a) OFF: Ic=0 because Ib=0 or voltage across base-emitter is lower than 0.7 V.
b) ON: Ib is the maximum possible in the circuit because Ic is high

14a Look at circuits A and B and identify which circuit the two descriptions refer to.

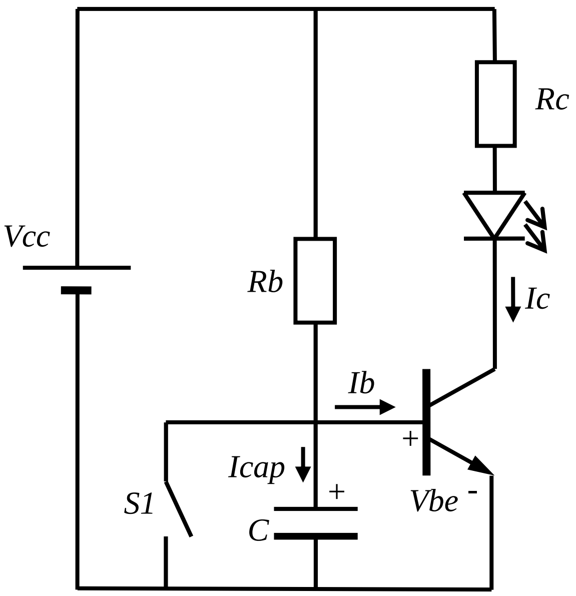


Circuit ______: When the switch is ON a current passes through the resistor into the base of the transistor. Then the transistor allows collector current to flow and the LED comes on.

Circuit _______:When the switch is ON the voltage across base-emitter comes to 0. Then the transistor doesn't allow collector current to flow and the LED goes off.

14b In this circuit the transistor also works as a SWITCH. The capacitor charges through Rb. Rb and C form a voltage divider for timing purposes. Try to predict how the circuit works.

When S1 is on ....



....

and the LED is ....

When S1 is off the capacitor ....and the LED is .... When voltage across the capacitor reaches V

....

....

.... and the LED is .... until

....

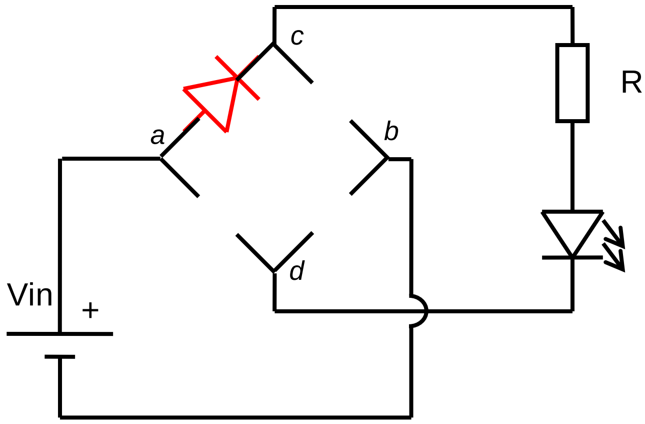
....

Self assessment: In the next unit you are going to learn about digital electronics. Before you move on make sure that you can answer yes to all these questions.

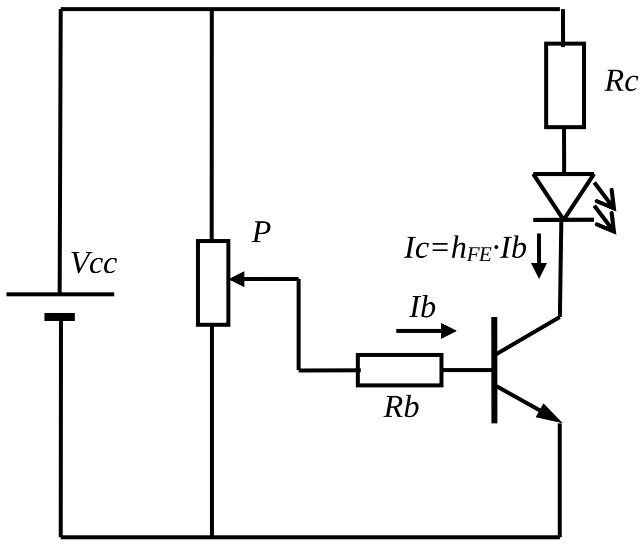
QUESTION	No	More or less	Yes
Can I get the value of a resistor using the colour code and use multiples to express it?			
Can I list the different types of resistors, draw their symbols and explain possible applications?			
Can I calculate voltage in simple voltage dividers?			
Can I describe and calculate charge and discharge of a capacitor in RC circuits?			
Can I calculate currents in circuits with diodes and resistors?			
Can I explain how a transistor works in a circuit, both as a switch or as an amplifier?			
Can I interpret diagrams and identify components to build simple circuits?			

2.5 Building real circuits.

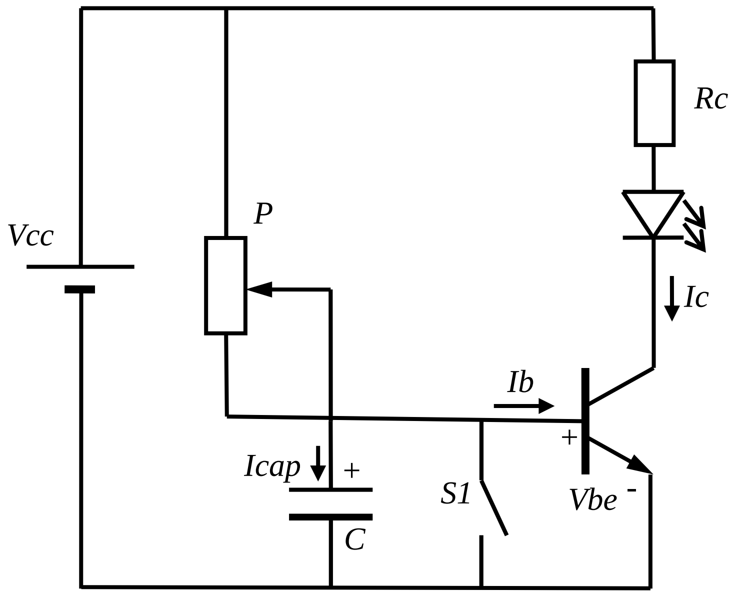
2.5.1 Rectifier bridge.



2.5.2 Light regulator.



2.5.3 Timer.



3 DIGITAL ELECTRONICS.

3.1 The binary numeral system.

The DECIMAL system, or base-10, represents numeric values using 10 symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9.

The BINARY numeral system, or base-2 number system, represents numeric values using two symbols, 0 and 1.

Binary numbers are closely related to digital electronics. **With digital electronics a '1' means that a voltage signal is high and '0' means it is low**. The binary system is used internally by all modern computers.

1 What electronic component can work as a binary switch? ....

When we put together many of them in a single piece of silicon it is called ....

In computing and telecommunications a binary digit is called a _ _ _. It is the basic unit of information in a binary system.

2a The binary system is positional, like the decimal one. To count in binary we put in "ones" from the right. Look at the table on the right and try to figure out the rule. Fill in the missing digits.

Binary	Decimal	Binary	Decimal
0	0	1000	8
1	1	1___	9
10	2	___10	10
11	3	1011	11
100	4	1100	12
10_	5	1__1	13
1_0	6	1110	14
1__	7	1111	15
__00	8	1_____	16
1001	9	1_____	17

2b It is easy to CONVERT any binary number to decimal because each position has a weight.

Look at the example and convert binary numbers b), c) and d) to decimal. Check the answers with your partner.

	Binary	Binary weight						Decimal
		32	*16*	*8*	*4*	*2*	*1*	
a)	001100	0	0	1	1	0	0	8+4=12
b)	010101							
c)	101010							
d)	100001							

What is the decimal equivalent of one one zero?

2c In order to convert from decimal to binary you have to do the inverse process. Convert the following numbers and check your answers with your partner orally.

	Decimal	Binary weight						Binary
		32	*16*	*8*	*4*	*2*	*1*	
a)	41							
b)	20							
c)	33							
d)	63							

Adding binary numbers is a very simple task. As with decimal numbers, you start by adding the bits (digits) from right to left:

Rules	Examples		
0+0 = 0		*11 1*	*11*
1+0 = 1	1001100	1001001	1000111
0+1 = 1	+ 0010010	+ 0011101	+ 1010110
1+1 = 10	---------	---------	---------
1+1+1 = 11	1011110	1100110	10011101

It is also possible to subtract, multiply and divide. This is how electronic devices operate.

3a Add the following numbers. Your teacher will ask some of you to read the additions to all the class. Follow the example and practise reading the procedure to prepare.

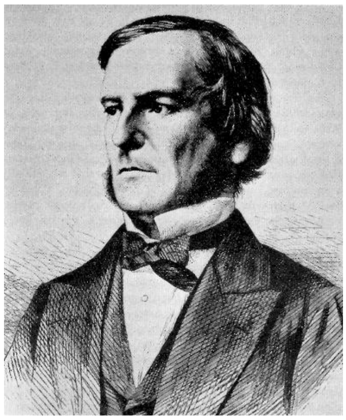
```
    1
   001  (1)
 + 101  (4+1=5)
 -----
   110  (4+2=6)
```

One plus one equals zero and I carry one.
One plus zero plus zero equals one.
Zero plus one equals one.
The result is one one zero in binary, which is six in decimal.

```
a)
    0011
  + 1010
  ------
```

```
b)
    1011
  + 0111
  ------
```

3.2 Boolean logic. Logic gates.


George Boole (1815-1864)

In the last lesson you used BINARY DIGITS to represent NUMERIC VALUES.

BINARY DIGITS can also be used to represent LOGIC STATES like “true” (1) or “false” (0).

BOOLEAN LOGIC (or Boolean algebra) is a complete system for logical mathematical operations. It was developed by the English Mathematician and philosopher George Boole in the 1840s. Boolean logic has many applications in electronics, computer hardware and software, and is the basis of all modern digital electronics.

These are examples of Boolean operations:

1 or 0 = 1	1 and 0 =0	not 0 =1	1 and 1= 1	0 or 0 = 0	not 1 = 0

4a Read the text about Boolean operation representation and fill in the table with the expressions below.

Boolean algebra is based on these logical operations: conjunction $x \wedge y$ (AND), disjunction $x \vee y$ (OR), and complement or negation $\neg x$ (NOT).

In electronics, the AND is represented as a multiplication, the OR is represented as an addition, and the NOT is represented with an overbar

General	*Maths*	*Electronics*
a AND b		
a OR b		
NOT a		

$a \vee b$	$\overline{a}$	$a \cdot b$	$\neg a$	$a + b$	$a \wedge b$

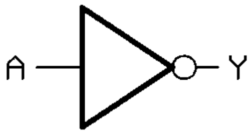
Digital circuits are built from simple on/off switches called **GATES**. These gates have two states: logic high (ON or 1) and logic low (OFF or 0). **TRUTH TABLES** are used to analyse all the possible alternative states of a digital circuit.

You can see the gates symbols on next page. There are two sets of symbols for gates: The traditional ones from America and the new square symbols, a standard by the IEC (International Electrotechnical Commission). You should use the IEC symbols. Anyway the traditional ones are still widely used for simple gates.

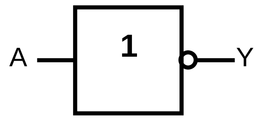
4b Read the gate descriptions and fill in the truth table for each one.

NOT gate: A NOT gate or inverter has just one input. The output is ON if the input is OFF, and OFF if the input is ON.

$Y=\overline{A}$



NOT symbol

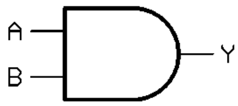


NOT IEC symbol

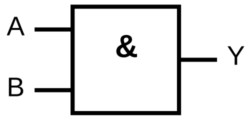
A	Y
0	
1	

AND gate: The output is ON (1) if **both** input signals are ON (1).

$Y=A\cdot B$



AND symbol

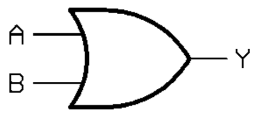


AND IEC symbol

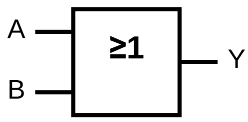
A	B	Y
0	0	
0	1	
1	0	
1	1	

OR gate: The output is ON if **either** or both inputs are ON.

$Y=A+B$



AND symbol

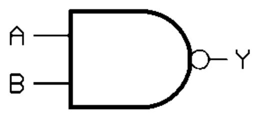


AND IEC symbol

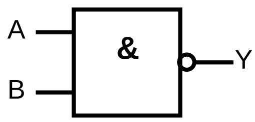
A	B	Y
0	0	
0	1	
1	0	
1	1	

NAND gate: The output is ON **unless both** inputs are ON.

$Y=\overline{A\cdot B}$



NAND symbol

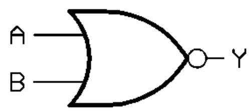


NAND IEC symbol

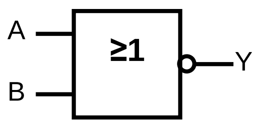
A	B	Y
0	0	
0	1	
1	0	
1	1	

NOR gate: The output is ON if both inputs are OFF.

$Y=\overline{A+B}$



NOR symbol

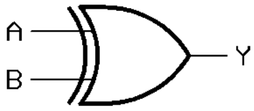


NOR IEC symbol

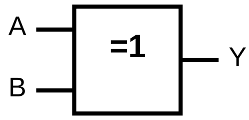
A	B	Y
0	0	
0	1	
1	0	
1	1	

XOR gate: The output is ON if one input is ON and the other is OFF, but will not work if both are ON.

$Y = A \oplus B$



XOR symbol



XOR IEC symbol

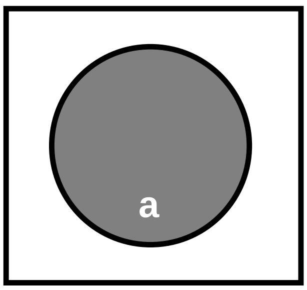
A	B	Y
0	0	
0	1	
1	0	
1	1	

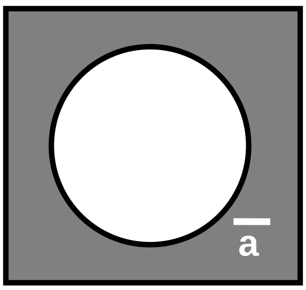
4c Let's test if you remember the IEC symbols and the truth tables. In turns, choose one gate and ask your partner for the function description and the IEC symbol gate. Here you have an example:

Can you explain how a NAND gate works?
What is the symbol of a NAND Gate?

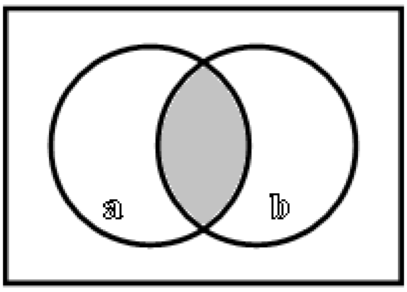
In a NAND gate the output is 0 when both inputs are 1.
It is a square with a "&" symbol inside and with a small circle at the output.

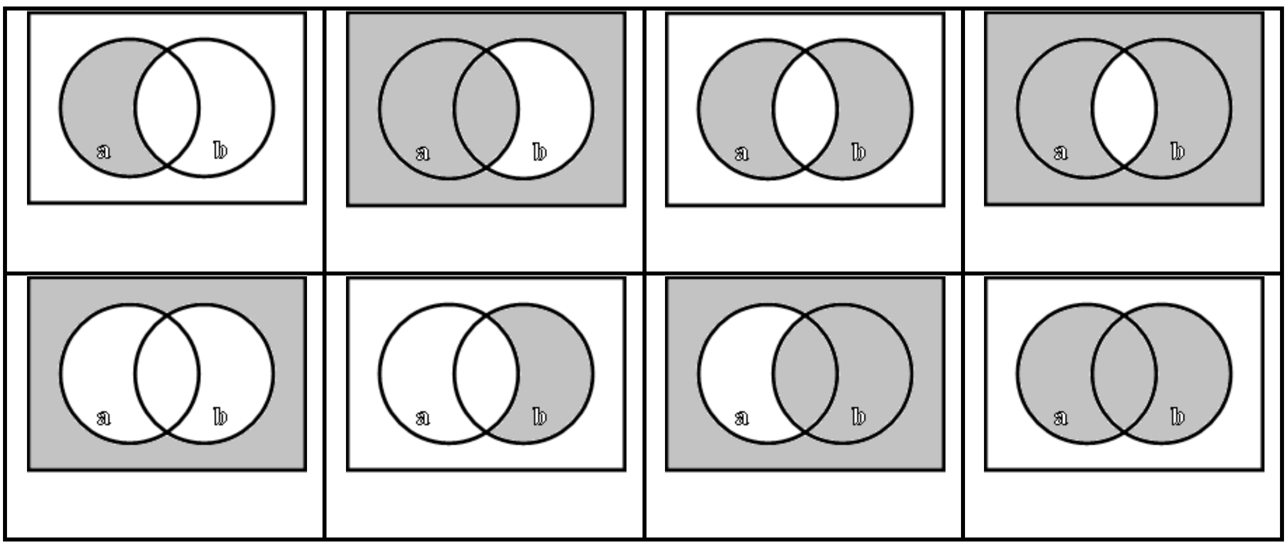
4d It is possible to represent logic functions with Venn diagrams. Look at the examples. Then identify the 8 diagrams as $\overline{a}\cdot b$, $a\cdot\overline{b}$, $a+b$, $\overline{a}+b$, $a+\overline{b}$, $a\oplus b$, $\overline{a\cdot b}$, $\overline{a+b}$.





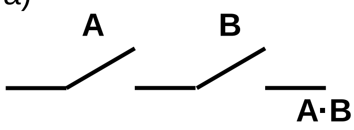
$a\cdot b$



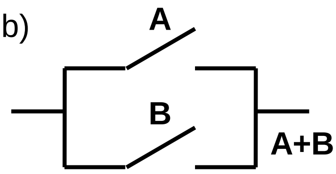


5 Logic functions can be implemented **electrically with switches** as in these examples.

a)



b)



a) AND: The output will only be on when both switches A and B are on.
b) OR: The output will go on if either switch A or B is on.

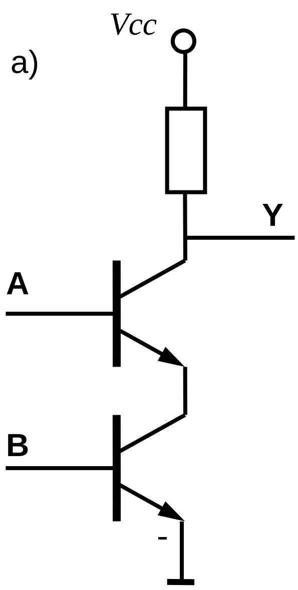
Real electronic gates are implemented **with transistors**. High voltage means 1 and low voltage means 0. These are simplified circuits of a NAND and a NOR gate. Think how the circuits work and fill in the blanks with these words:

parallel	high	low	NAND	series	NOR

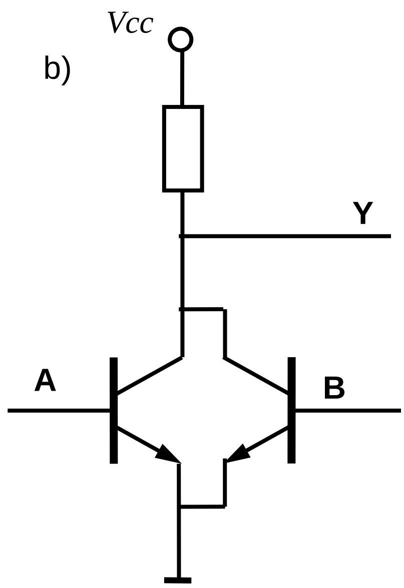
In circuit "a" both transistors are connected in _________. The output will go low only when both inputs are ________. So it is a ______ gate.

In circuit "b" both transistors are connected in ________. If either input goes up the output goes _______. So it is a _______ gate.

a)



b)

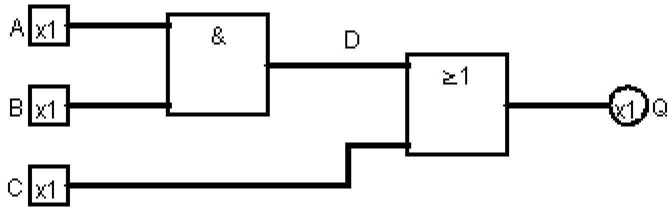


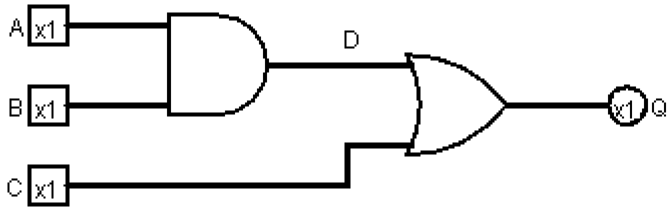
3.3 Logic circuits.

Logic circuits can have many gates, many inputs and more than one output. In this lesson we are going to work with circuits that have a maximum of 3 inputs and 1 output.

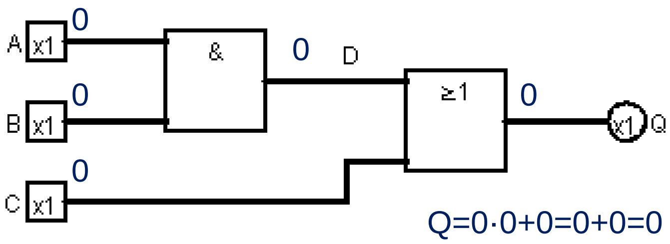
6a The diagram below shows a complex logic gate combining two simple gates. There are three inputs and eight possible outcomes. To complete a truth table go row by row. For each combination of input find first D and then Q.

The two first combinations of the truth table are done as an example. Complete the 6 remaining values.

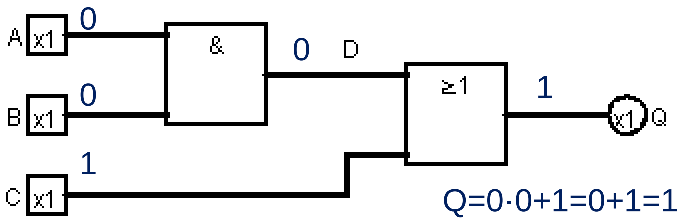




Expression: Q=A·B+C



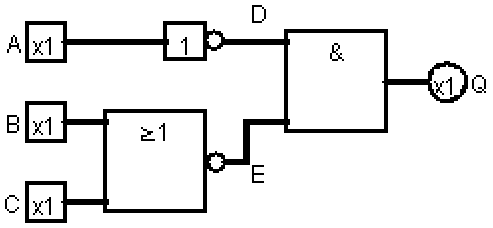
Q=0·0+0=0+0=0



Q=0·0+1=0+1=1

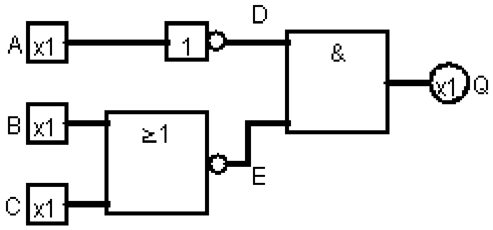
A	B	C	Q
0	0	0	0
0	0	1	1
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

6b For the next circuit find the expression, draw the gate diagram with the traditional symbols and complete the truth table.



IEC diagram *Traditional diagram*

Expression:



A	B	C	Q

7 You have to describe orally a logic circuit from the A/B worksheet to your partner. Your partner will describe one for you. Draw the diagram using IEC symbols.

Then you must find the logic expression and fill in the logic table. Finally check results with your partner.

This is an example of descriptions for the circuit in exercise 6b:

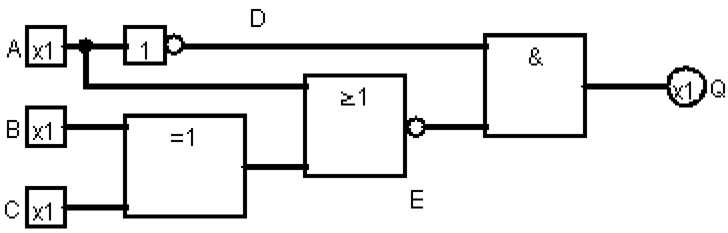
Input A is fed to an inverter. The output from the inverter is called D. Inputs B and C are fed into a NOR gate, whose output is called E. D and E are fed through an AND gate to output Q.

Circuit:

A	B	C	Q

Expression: Q=

8 For the next circuit find the expression, draw the gate diagram with the traditional symbols and complete the truth table.



Expression:

Traditional diagram:

A	B	C	Q

Look at the example in order to do exercise 9.

DESIGN A LOGIC SYSTEM to control heating like this: In automatic mode heating must be on when it is cold and there is somebody inside. In forced mode heating is always on.

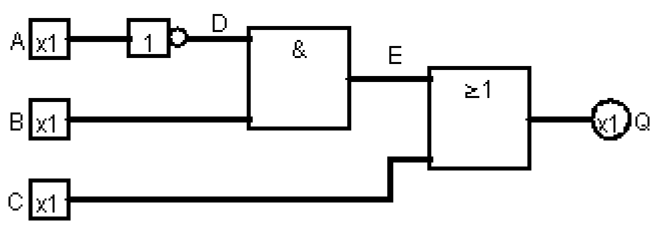
Inputs:
A: temperature (0 cold, 1 warm)
B: presence (0 nobody, 1 somebody)
C: mode (0 automatic, 1 forced)

Output:
Q= heating (0 off, 1 on)

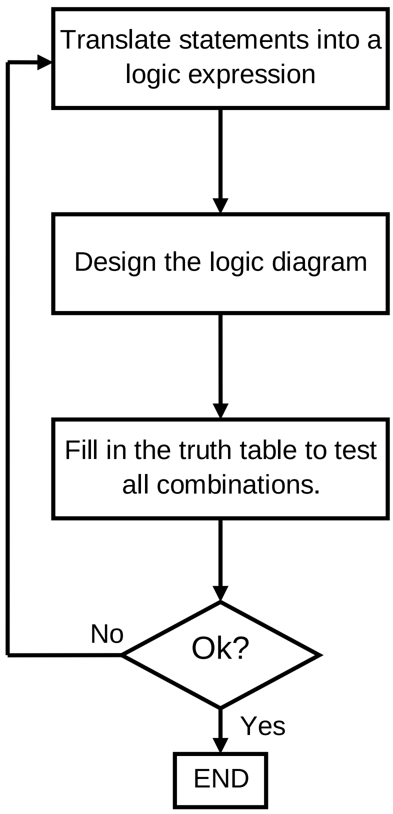
Design process:

Heating= (NOT temperature AND presence) OR mode

$$Q=(\overline{A} \cdot B) + C$$



A	B	C	Q
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1



9a Design a logic system to control an automatic light like this: The light must come on when it is dark and somebody passes in front of it.

Inputs:
A: presence (0 nobody, 1 somebody)
B: light_sensor (0 dark, 1 light)

Output:
Q= light (0 off, 1 on)

Expression:

A	B	Q
0	0	
0	1	
1	0	
1	1	

Diagram:

9b Design a logic system to control an alarm bell like this: the alarm bell must ring when the alarm switch is on and either the window or the door are opened.

Inputs:
A: window_open(0 closed, 1 open)
B: door_open (0 closed, 1 open)
C: alarm_switch (0 off, 1 on)

Output:
Q= alarm_bell (0 off, 1 on)

Expression:

A	B	C	Q

Diagram:

SELF ASSESSMENT: Before you move on make sure that you can answer yes to all these questions.

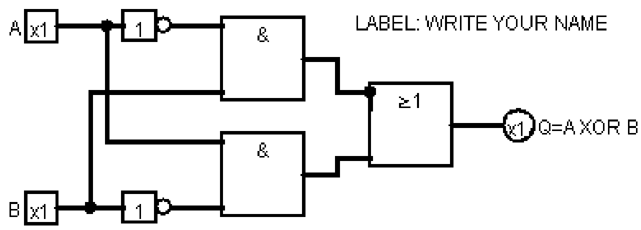
QUESTION	No	More or less	Yes
Can I convert between decimal and binary?			
Can I add binary numbers?			
Can I operate using Boole algebra?			
Can I translate logical expressions to gates?			
Can I obtain truth tables from a logic system?			
Can I use simulators to analyse logic systems?			
Can I design logic circuits in order to solve simple technological problems?			

3.4 Simulation work.

You are going to simulate logic systems with the logisim free software. You can download it from this web page: http://ozark.hendrix.edu/~burch/logisim/index.html.

3.4.1 Logisim basics.

Practice 1: Follow your teacher's instructions to build a XOR gate with AND, OR and NOT gates. Label the final design with your name.



Practice 2: Build and simulate the design you did in activity 9b to control an alarm system.

3.4.2 Automatic design of logic circuits.

Practice 3: Enter this expression: $Q = A \cdot \overline{B \cdot C} + B$ into logisim and use the *Combinational analysis* tool to build the circuit automatically.

Practice 4: Design a detector of prime numbers. The input will consist of four binary digits and the output has to be 1 when the input combination is a prime number (2, 3, 5, 7, 11 or 13). Use the *Combinational analysis* tool to set the truth table and get the circuit automatically.

3.4.3 Adding and visualising.

Practice 5: Using libraries with integrated circuits.

Electronic gates are implemented in integrated circuits. The 74XX series of logic gates is built with bipolar transistors. Follow your teacher's instructions to download the 74XX library from http://ozark.hendrix.edu/~burch/logisim/. It is called *7400 series Logisim library from Ben Oztalay*. Load it on *logisim.*

You have to find out what pins and what circuits to use to build this logic function:

Q = (A NOR B) AND (NOT C)

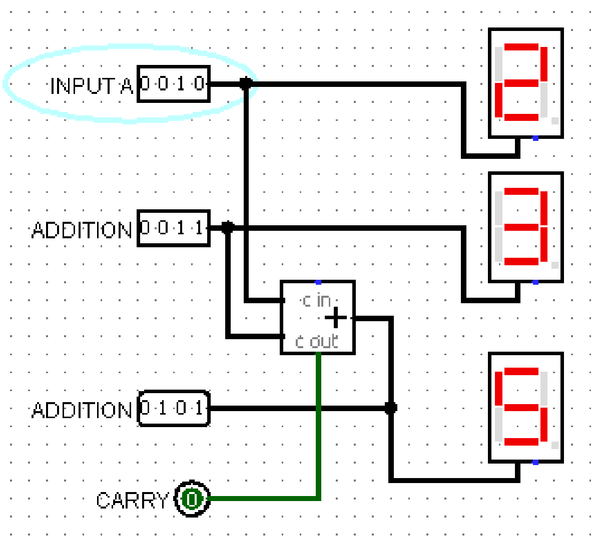
These are the microchips you may need to use:

- 7400: quad 2-input NAND.
- 7404: hex inverter.
- 7402: quad 2-input NOR gate.
- 7408: quad 2-input AND gate.
- 7432: quad 2-input OR gate.

Practice 6: Using Adding binary numbers with logisim.

Build the circuit in the picture. You will need:

- Normal inputs and outputs set to 4 bits.
- An *adder* from the *Arithmetic* folder.
- Three *hex digit display* from the *Input/output* folder.



The hexadecimal code has 16 different digits. What are they?

4 Revision.

Visual summary You have to create a visual summary of the three units. It has to fit on one page. It can't include sentences, just key words. It has to include: a time line, diagrams (tree, Venn...), formulae, symbols, circuits, samples, calculations, truth tables, etc. First you have to do it individually on a blank sheet of paper. Later you will do group work and agree on a final version that you have to write on this page.

Teaching activity. The following box contains all the topics that will be in the final exam. You will be given a number to work on one of the topics. You have to prepare an activity about that topic, similar to the ones you did during the lessons. Prepare the answer key too. You may have to teach that activity or be asked to solve some of your partner's activities on the board.

1- Questions on the history of electronics.	2- E-waste
3- Electronic block diagrams.	4- Analogue/digital/binary.
4- Ohm's law.	5- Resistor colour code.
5- Types of resistors.	6- Potential dividers.
7- Capacitors, types and units.	8- Charge and discharge of a capacitor.
9- Diodes: function and types.	10- Current calculations for diodes.
11- Transistors: function, parts and types.	12-Transistor as an amplifier: circuit description and calculations.
13- Transistor as a switch: circuit description.	14- Binary-decimal conversion.
15- Binary addition.	16- Basic logic operators: gates and symbols.
17- Logic circuits analysis with 3 inputs and 3 gates.	18- Logic system design with 2 or 3 inputs.

Useful language. Here you can write down all new vocabulary and useful expressions.

Vocabulary:

Expressions: