DIGITAL ELECTRONICS

For New Lower Secondary Curriculum
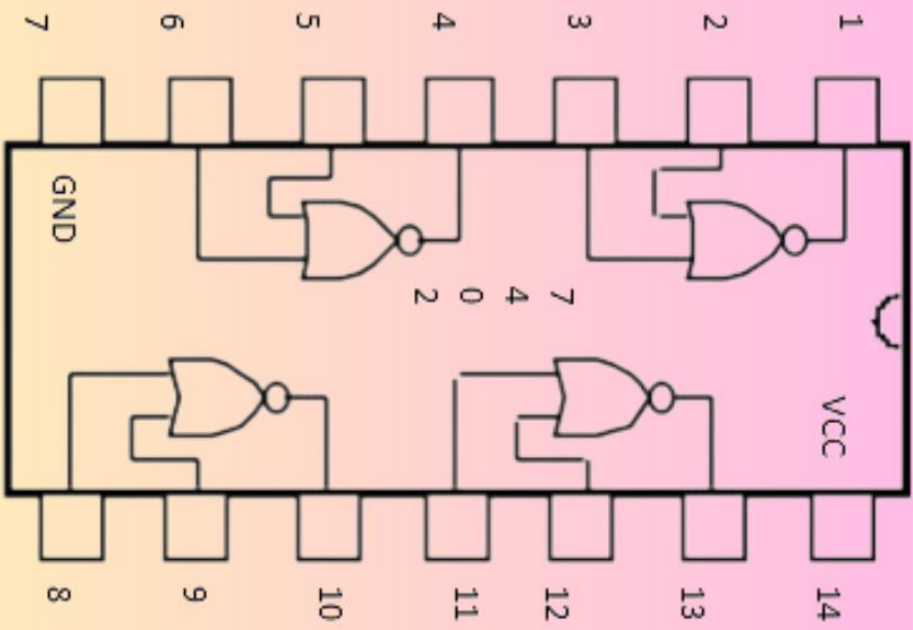
BYAKATONDA DENIS

DIGITAL ELECTRONICS

(Modern Physics: Part III)

NEW LOWER SECONDARY CURRICULUM

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Introduction

In general, electronics is a branch of physics that deals with the study, design and use of devices that control the flow of electric current (or electrons) in certain components to perform electrical functions.

Most electronic devices in use today have circuit boards with hundreds, thousands, millions or even billions of electronic components such as resistors, capacitors, inductors & more. These components are the ones that process and control electric current (or electric signals) to produce the desired outcomes.
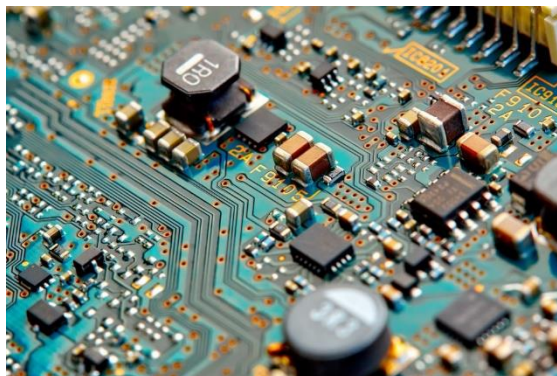
The electric signals are classified into two categories; *Analog & Digital.*

Analog signals are continuous signals that vary smoothly over time and can take on any value within a given range; Analog quantities include light intensity, sound intensity, and temperature; these quantities can take on any value within a given range.

In real life, we can take an example of a quantity such as human height to be analog since humans can be any height ranging from 1 foot to 7 feet, 1.3ft, 4ft, 6.3ft, ... there's literally an infinite number of values between 1 and 7 that can be someone's actual height. (please note that the range of 1 to 7ft use in this example is not absolute, there are some rare cases of people who may be outside this range).

On the other hand, *digital signals* are discrete signals that can only take up specific values or states within a given range. In electronics, digital signals usually take up one of the two values or states; ON or OFF, 1 or 0, HIGH or LOW, TRUE or FALSE.

Again, using a real life analogy, a quantity such as population of a class is an example of a digital quantity, a school can have 5,6,7, ... students but not like $12\frac{1}{2}$ or $34\frac{1}{4}$ students! Human life itself has two only 2 possible states, ALIVE or DEAD (strictly speaking), and we can consider it digital.

Digital electronics is a branch of electronics which deals with systems that use of digital signals for their operation. Such systems process and store information digitally, they include computers, digital clocks, digital decoders and more.

Comparison of Digital and Analog Electronics

The graphs below illustrate the difference between an analog and digital volgate signal. Notice how the graph for analog signals is continuous and takes on any values within the range of 0 to 5, while the graph of a digital signal only takes up 2 specific values or states, 0 or 5, nothing in between.
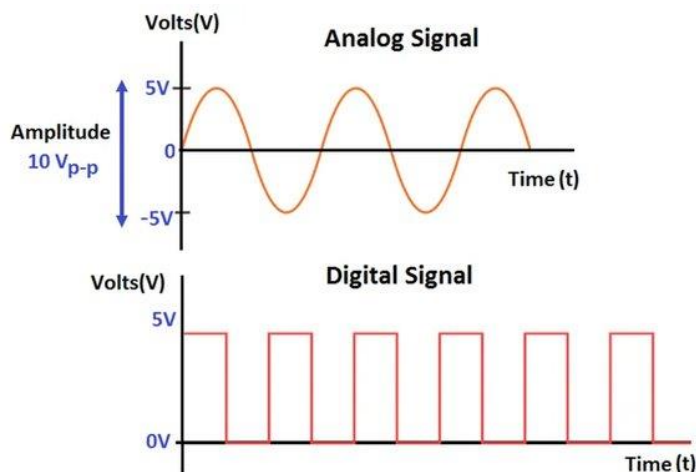
	Digital electronics	Analog electronics
Signal type	They use discrete signals or states (e.g. 0 or 1)	They use continuous signals
Noise resistance	They are less prone to noise and interference	They are more likely to be affected by 'noise'
Complexity	It is easier to design complex digital circuits	It is quite hard to design analog circuits for certain complex applications.

DIGITAL CIRCUITS

These are circuits specifically designed to process digital signals. They use logic gates to perform logical operations like addition, subtraction, and comparison.

Logic Gates

Logic gates are the basic building blocks of all digital circuits. They receive signals from input devices and then perform logical operations (or decisions) to produce a single binary output.

There are 3 basic logic gates upon which complex ones are built, these are; the NOT gate, AND gate & OR gate.

The NOT or INVERTOR gate

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The invertor gate is one that inverts the input signal.

As the name suggests, the invertor gate works by inverting whatever the input signal is, to invert means to change the input signal to its opposite, as an example, if the input signal is a HIGH, the output will a LOW which is the opposite, or using binary presentation, if the input is a 1, the output is a 0, if the input is a TRUE, the output is a FALSE.

Below is a symbol for the NOT gate;
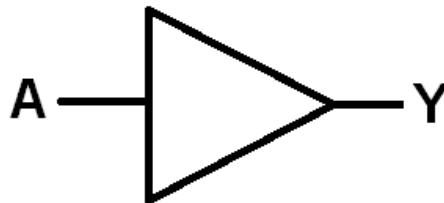
To best understand how a logic gate works, we often draw a *truth table*. A truth table is a table that shows all the possible inputs of a given logic gate and their possible outputs.

While drawing a truth table, we may choose to represent the inputs and outputs in one of the following formats;

Binary	Boolean logic	Voltage	Integers
1 or 0	True (T) or False (F)	High (H) or Low (L)	+ or -

For simplicity, we shall be using the binary format and the Boolean logic format.

The truth table for a NOT gate is as follows;

Input	Output
1	0
0	1

From the truth table above, we can see that when the input is a 1, the output of the gate is 0 and when the input is a 0, the output is a 1.

Automatic street lights use the logic of the NOT gate, i.e. when the sunlight is ON during the day, the lights are OFF and when the sunlight is OFF at night, the lights are ON.

Can you think of other real life examples of systems that use this kind of logic?

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The AND gate

The AND gate is one whose output is TRUE (or 1) if and only if all its inputs are TRUE (or 1's).

The figure on the side is a symbol for the AND gate and its truth table.
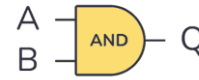
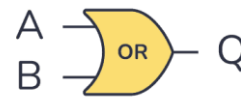| A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

It is a two input AND gate. A and B are the inputs while Q is the output. The AND gate will only output a 1 if both inputs are 1's as seen in the truth table.

As an example of the AND gate's logic, for one to travel to abroad, they must have both a passport and a visa. If one has only a passport but without a visa or a visa without a passport, they are not allowed.

Imagine if you're home security system, since most security threats occur at night, you would want it to be triggered at night, but that's not enough, not all nights have security threats, so you need to add a second condition, let's say movement in the compound; in this case, your security system (such as an alarm) will only be triggered if it is at night and there's movement in the compound. Both conditions must be true for the output to be true.

The OR gate

This is a logic gate whose output is TRUE (or a 1) if at least one of it's inputs is a TRUE (or a 1).

Unlike AND gates where both inputs must be 1's for the output to be a 1, the OR gate requires at least one input to be a 1 for the output to be 1.

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

As an example, one is allowed to purchase items from a supermarket if they have either a credit card or cash money; of course having both is to the buyer's advantage but at least one of them is needed. (and yes, I know this isn't a perfect example since in practical cases, no one would have to use both at the same time).

In some home security systems, panic buttons are placed in each bedroom and when at least one of the buttons is pressed, the alarm is sounded, even when all the buttons are pressed at once, the alarm still sounds.

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COMBINATIONAL LOGIC GATES

Sometimes, we need to create electronic systems or computer programs whose logic (or decision making) is more complex than what is described by the logic gates described thus far. To accomplish this, we make use of combinational logic.

By combining the three basic logic gates described above, we can create other logic gates; two popular ones are the NAND gate and the NOR gate.

The NAND gate

The NAND gate is a gate whose output is a 0 if and only if all its inputs are 1.

It is made by connecting a NOT gate in front of an AND gate; basically the NAND gate's output is an inversion (opposite) of the AND gate.

Below is a symbol and truth table for the NAND gate.

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

Can you think of scenarios where such kind of logic would be needed or used?

The NOR gate

This is a logic gate that gives an output of 1 if and only if all its inputs are 0.

The symbol and truth table are given below.

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

Can you think of scenarios where such kind of logic would be needed or used?

There are other combinations of logic gates that do not have formal names; thankfully, we can still draw their truth tables and analyze the outputs.
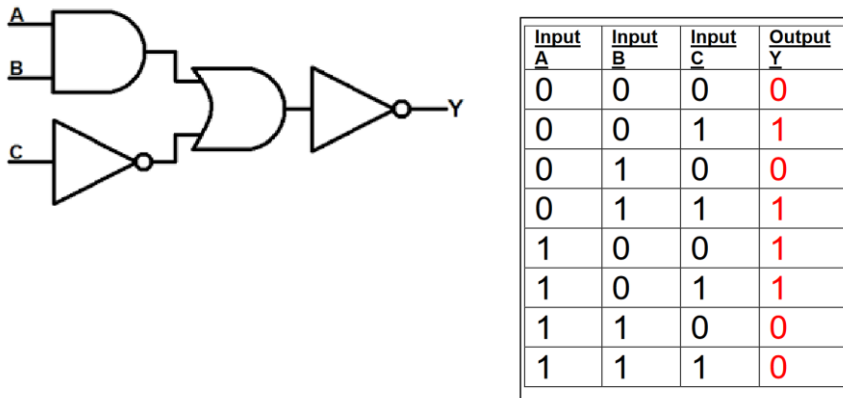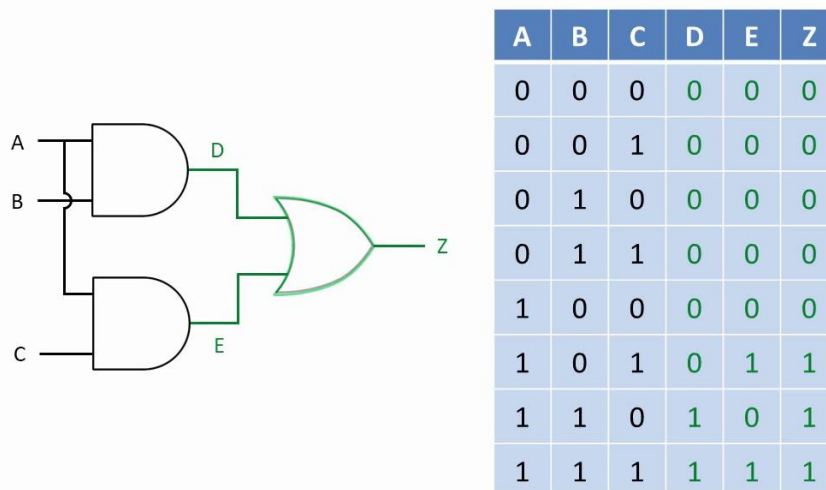
Below are some examples;

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Example 1

A	B	X	Y	Q
0	0	0	1	1
0	1	0	0	0
1	0	0	1	1
1	1	1	0	1
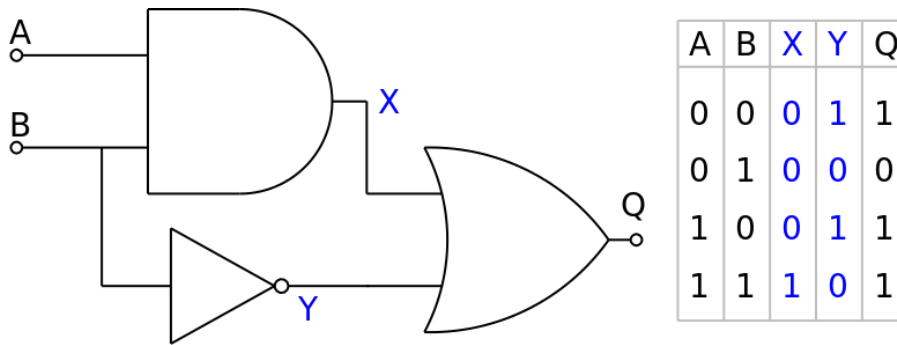
In the example above, the main output terminal is **Q**, and the main inputs are **A** and **B**; the intermediate outputs, **X** and **Y** are not a requirement in the truth table but we have added them to easily tell the output **Q**.

Example 2

Input A	Input B	Input C	Output Y
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	0

Example 3

| A	B	C	D	E	Z
0	0	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	1

Take a look at the input terminal **A**, it is also connected to one of the inputs of the lower AND gate, note how the line 'jumps' terminal **B** to imply that there's no connection there.

APPLICATIONS OF LOGIC GATES

Logic gates are the cornerstone of modern digital electronics used in almost every household. Television sets, phones, radios, computers are all made of integrated circuits (ICs) which are made of millions or even billions of logic gates.
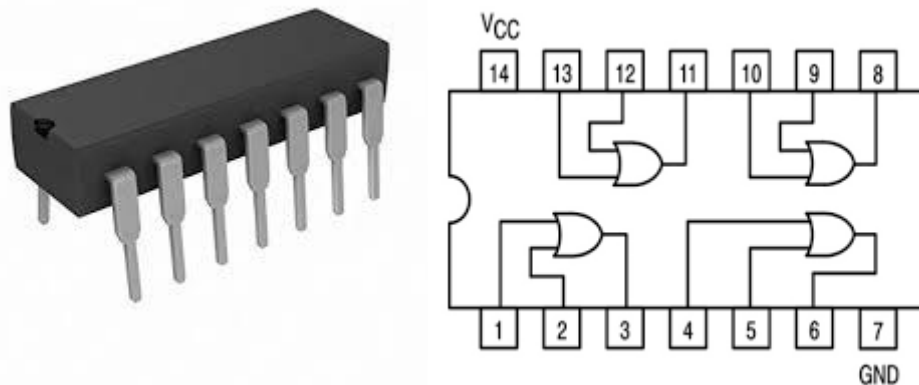
(Left: Picture of an IC, most digital electronics are made up of ICs since it is an efficient way to pack many logic gates in a small form factor. Right: Internal block diagram of an IC showing logic gates, some terminals are inputs while others are outputs)

Bistable switches

Another popular application of logic gates is in bistable switches.

A bistable switch is a type of circuit that has two stable states. It can stay in one of these states until it is triggered to switch to the other state. This concept is fundamental in digital electronics, particularly in memory storage and various types of electronic devices.

Think of a bistable switch like a light switch that can either be ON or OFF. Once it's ON, it stays ON until you turn it OFF, and vice versa.

One of the simplest types of bistable switches is called an **SR Latch**. It's made from two NOR gates or two NAND gates. The SR latch is a basic memory circuit used to store a single bit of data. By combining many of these circuits, we can form larger memory devices such as those used in phones & computers.

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SR Latch

S	R	Q	$\overline{Q}$
0	0	1	0
		0	1
0	1	0	1
1	0	1	0
1	1	0	0
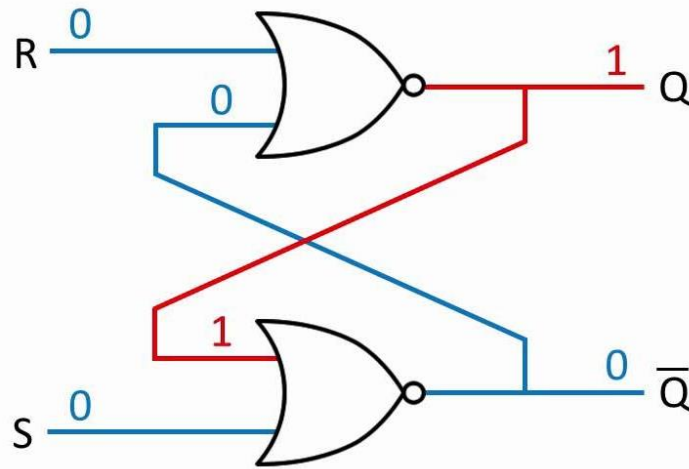
The inputs are **S** (Set) and **R** (Reset).

- When **S = 1** and **R = 0**, **Q = 1** (Set state).
- When **S = 0** and **R = 1**, **Q = 0** (Reset state).
- When **S = 0** and **R = 0**, **Q** stays in its previous state (either 0 or 1).
- When **S = 1** and **R = 1**, it's an invalid state for **NOR** gate SR Latch.

Review Questions On Logic Gates

1. Describe one scenario in real life that uses AND, NAND, OR & NOR logic gates, in each case, draw a truth table to describe the outcomes.

2. As a physics student, you are tasked to design a home security light control circuit using the basic logic gates; the light should be activated by either manually pressing a switch or automatically by a light sensor; the sensor works as follows, when there's sunlight outside, it switches off the light but when there is darkness, it switches on the light. Draw a logic circuit diagram and a truth table for all the possible operations.

3. An Indian investor Ramesh sells expensive watches in Kampala, he however faces a problem that sometimes, customers lift off watches from their shelves and steal them. He has been advised to place each watch on an electronic button switch which should be ever on (due to the weight of

the watch that will be pressing it down); he wants the circuit to operate such that when a watch is lifted off from the shelf, an alarm is activated. Using logic gates, show how this can be achieved; include a truth table for your diagram.

4. A greenhouse farmer has 2 sensors in his greenhouse; a temperature sensor and a humidity sensor. the plants in his greenhouse can't give good yields if the temperatures are above $35^{\circ}C$ or if the humidity is HIGH. He wants an alarm to be sounded if the plants are not having appropriate conditions for giving good yields, using any logic gate or a combination of logic gates, describe how this can be achieved.

5. Draw truth table for the following combinational logic circuits.
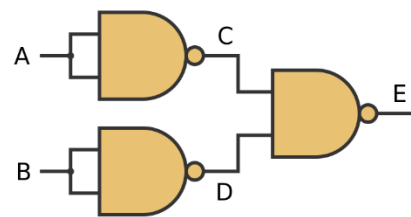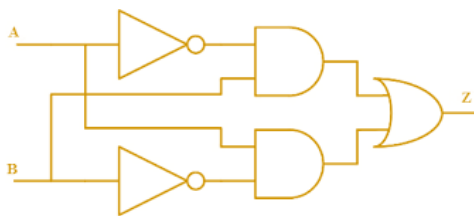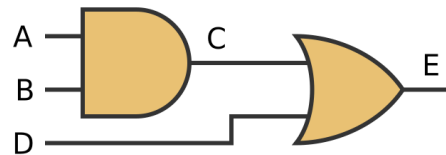

POTENTIAL DIVIDERS

A potential divider is a circuit that divides a given voltage into two or more smaller voltages.

Suppose we have a 12 V battery as your source of electricity, but we want to power a lamp which can only handle a maximum of 8 volts, what do we do? Well, we divide the 12 V potential into 2 portions, a portion of 4 V and another of 8 V, that way, we can safely connect out battery to the 8V portion without damaging it. In fact, we can keep varying the voltage portions to change the brightness of our bulb.

To accomplish the process described above, we use a potential divider circuit; a circuit that divides a given voltage into two or more voltages.

Potential dividers are made by connecting two or more resistors in series; each resistor opposes the flow of current through it creating a potential drop between its ends, hence creating a potential difference, which is usually a fraction of the total voltage.

Consider two resistors R1 and R2 connected in series across a 12 V battery.
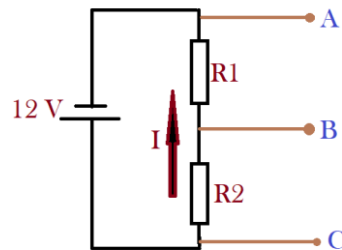
Terminals A, B & C are connected across the 2 resistors; let V_{AB} be the potential difference between A and B, and V_{BC} be the potential difference between B and C.

If $R_1 = 2\Omega$ & $R_2 = 4\Omega$, the total current flowing in the circuit is;

$$V = IR_T,$$

$$R_T \Rightarrow R_1 + R_2 = (2 + 4)\Omega$$

$$= 6\Omega$$

$$\therefore I = \frac{12}{6} = 2A$$

Now, the voltage (or more specifically, the potential difference), across R_1 is;

$$V_{AB} = IR_1$$

$$V_{AB} = 2 \times 2 = 4\ V$$

And that across R_2 is;

$$V_{BC} = IR_2$$

$$V_{BC} = 2 \times 4 = 8\ V$$

(Notice that; $V_{AB} + V_{BC} = 12\ V$).

Anyways; with the right choice of resistors, we have created a potential divider circuit that splits the 12 V source into 4V and 8V, and now, we can safely connect our lamp to the terminals B & C since the potential difference across these terminals is 8V, which is the maximum our lamp can take.

In practice, an easier way to build potential dividers is by using a variable resistor (a resistor whose resistance can be adjusted, usually by turning or sliding a knob).

(Examples of variable resistors)

Some applications of potential dividers

1. Brightness control for lamps; using potential dividers with variable resistors, we can vary the potential difference across a bulb thus reducing its brightness. The circuit shows how a potential divider can be used to control brightness,
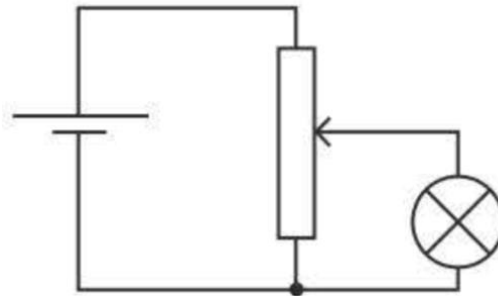

2. Volume control circuits; for some speakers, the volume depends on the voltage applied; thus by using potential dividers and a circuit similar to that above, we can control the volume of an audio device.

3. Adjustable Power Supplies; Potential dividers are used in adjustable power supply circuits to provide different voltage levels from a single power source. This is particularly useful in laboratory settings and for powering different stages of electronic devices that require various operating voltages.
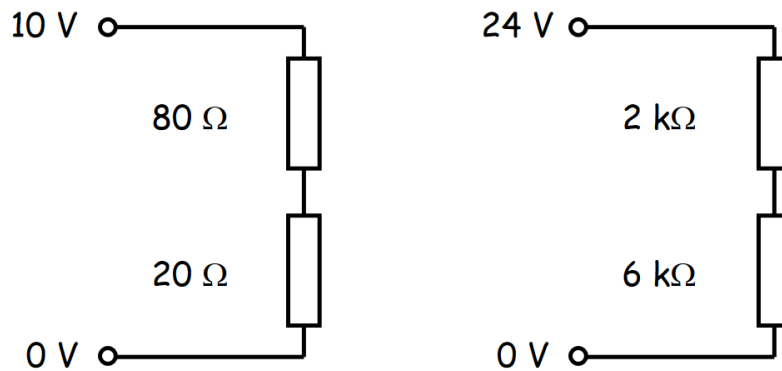

(An adjustable power supply)

Review problems on potential dividers

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1. In each of the circuits below, determine the unknown resistances and voltages.
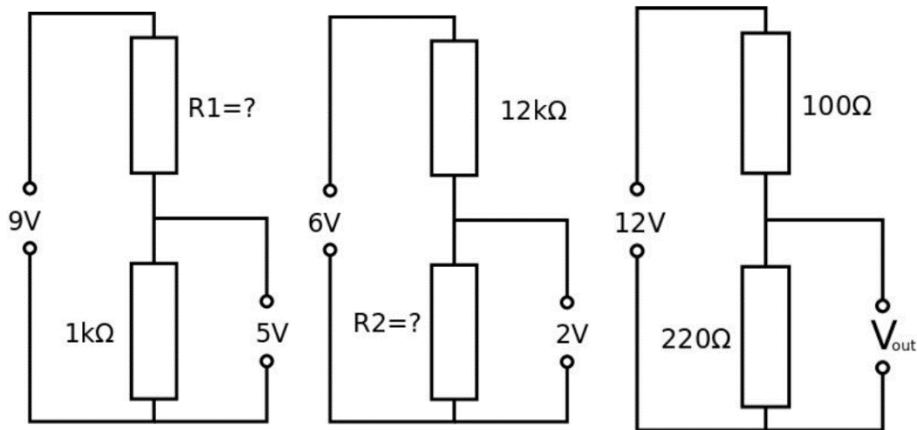
2. Find the voltage across each of the resistors in the circuits below.

3. The tables below show the resistances of a certain **LDR** (Light Dependent Resistor) and thermistor vary with external conditions.
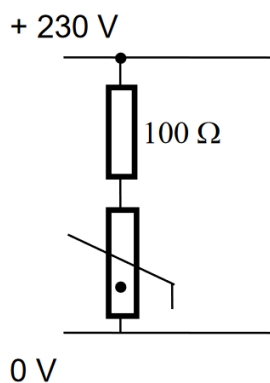
LDR

light condition	resistance (Ω)
dark	10 000
light	2 500
bright	20

Thermistor

temperature (^{o}C)	resistance (Ω)
10	4 000
40	1 980
100	200

Use the information in the tables to answer the questions below.
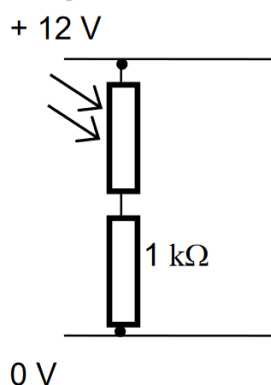
The following circuit is part of the input to an electronic frost alarm.

+ 230 V

100 Ω

0 V

Calculate the potential difference across the thermistor when it is

(a)   10 °C
(b)   40 °C

The following circuit could be part of a light meter for a camera.

+ 12 V

1 kΩ

0 V

Use the information above to find the potential difference across the LDR when it is:

(a)   dark
(b)   light