Crosswinds (Experimental)

An Introduction to Electricity and Magnetism

This version of the problem has been adapted as an experimental introduction to Electricity and Magnetism

Intended Learning Outcomes

By the end of this activity students should be able to solve problems involving:

- Resistances, current and voltages of series and parallel components
- Ohm's Law
- Kirchhoff's Laws
- Potential Dividers
- Capacitor voltage and resistance whilst charging and discharging
- RC circuits and their time constants
- Capacitor smoothing
- Dynamos
- Faradays law and induced current

Students will use the following skills:

- Designing of experiments to test a hypothesis
- Evaluating the errors in an experiment and their consequences
- Working as a team
- Report writing

KEYWORDS:

Capacitance, DC circuit, dynamos, electric current, electricity, experimental, Faraday law, induced current, Kirchoff's Laws, Ohm's law, potential dividers, RC circuit, resistance, time constant, voltage

Contents

The original version of 'Crosswinds are Critical' is run as a Laboratory Group Research Project for students on the Physics degree at the University of Leicester. It is undertaken by students in small groups. There are four laboratory sessions of 3 hours each as well as two facilitated workshops. For each of the workshops there is set question for class discussion, that are marked at the workshops. These workshop questions are designed to support the practical work by providing ideas and relevant theory. Most of the required theory can be found in any undergraduate physics text book.

Reading List

The following textbooks are suggestions, other equivalent textbooks are available:

- Breithaupt, J. ***Physics.*** Palgrave Foundations.
- Tipler, P.A. ***Physics for Scientists and Engineers***. Freeman.

Problem Statement

From a local newspaper:

CROSSWINDS ARE CRITICAL

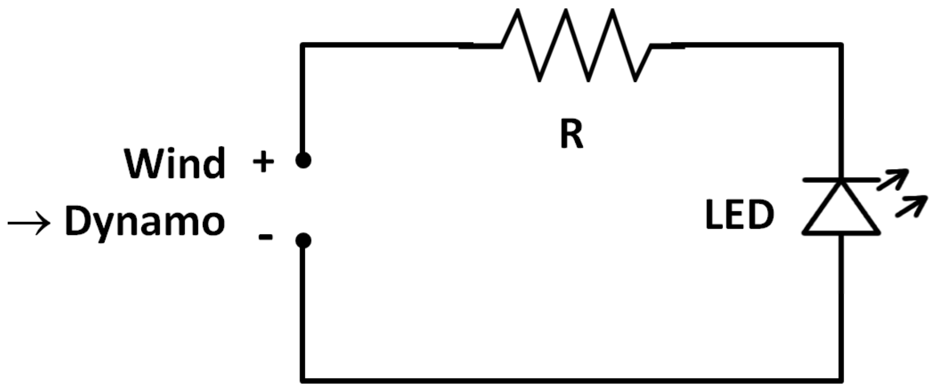
Another incident this week serves as a reminder for pilots to consider crosswinds on approach to land. Bob C's Puffin Aerosport suffered minor damage after a gust of wind affected the aircraft on landing. Bob was approaching runway 27 (due west), with air traffic control reporting wind from the north west at 21 knots. The Puffin is rated for crosswind components up to 15 knots, so Bob went ahead with his landing, only to be caught by a gust on touchdown. The plane veered onto the grass at the side of the runway and bent an undercarriage leg. The airport emergency team arrived at the scene quickly, but Bob was unharmed and able to exit the aircraft unassisted. He intends to have the Puffin flying again within three weeks.

This is the second incident this year involving crosswinds. Pilots are advised to read the operating manuals for their aircraft to determine crosswind limitations and operating procedures. When on approach, monitor the wind information given by air traffic control and keep an eye on the windsock to assess gusting.

Asked if anything was being done about this state of affairs a spokesperson for Otherton Airport management said that they would be pleased to receive ideas for a safety beacon, but that this would have to get CAA approval.

From the Director of Research:

With regard to the safety beacon, I've got some data for you below on the laboratory equipment. Here's a suggested circuit. Do you think it will work?



We can add a capacitor to smooth the output if the wind is gusting.

Once you've given me the relevant data I can scale this up. We'll want to patent this so I need technical details in your report.

Suggested Deliverables

Individual or group reports to the director of research.

Laboratory Equipment Provided

All groups will be provided with:

- 1 x Domestic fan
- 1 x 24 Volt DC Motor
- 1 x Fan blade
- 1 x Capacitor (22000 µF)
- 1 x Pico Data logger
- 1 x Oscilloscope
- 1 x Fan adaptor collar
- 1 x Red L.E.D.
- 1 x Metre rule
- 1 x Bread-board
- 1 x Multi-meter
- 1 x Set of wire clippers/strippers

All groups should have access to:

- A range of resistors ranging between: 100 – 4.7×10^6 ohms
- A range of capacitors ranging between: 0.01 – 4700 microfarads
- Signal Diode
- Single core wire

- Loan of an Anemometer for a short time (three to be shared between groups)
- Access to dynamo driven at a specified speed (one to be shared by the class)

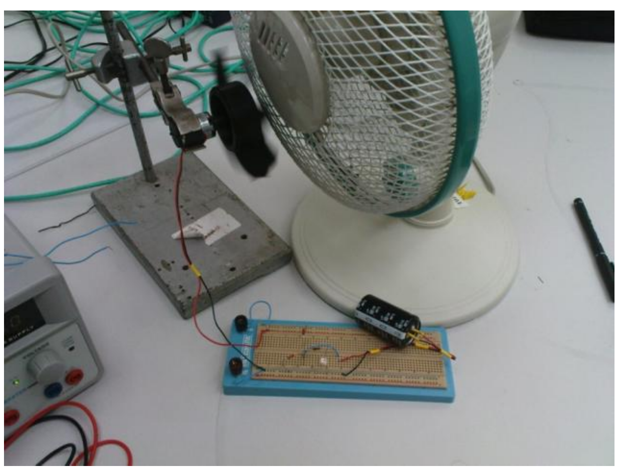
!

The LED requires a potential difference of 1.6 V in order to light up.

It will blow if the current exceeds 30 mA.

The typical output from the dynamo in the airflow from the fan is up to 5 V.

The I-V curve is provided in the Supplementary Information section.



Laboratory Sessions

Session 1

Locate the Problem

Several objectives have been suggested:

- Evaluate the proposed circuit theoretically (and practically provided you don't damage the LED)
- Design a potential divider
- Build and test it

Existing knowledge

Some of the topics which may be useful to research before attempting the given tasks are:

- Resistances of components in series and parallel
- Ohm's Law
- Kirchhoff's Laws
- Voltage drops across resistors in series
- Potential Dividers

Prevention of damage to LED:

A resistor which prevents the LED from blowing at 5V can be calculated if we assume the LED's resistance is insignificant at this voltage (which it is). Then we use Ohms law to calculate the current. To limit the current to 30mA, from 5V, we need a resistance of approximately 160Ω.

If this were used, a very large voltage would be required to activate the LED, reducing its useful range.

Session 2

Locate the problem

You are asked to research smoothing a voltage by the use of a capacitor. In this case, we want to smooth the output from the dynamo, which acts as the input voltage for our circuit.

You have been asked to calculate the time constant for an RC circuit, as well as measuring this value experimentally. You can then compare the two values in order to test whether or not the theory used is correct, or if there are any complications in the circuit you may not have considered.

The problem is therefore:

- Investigate the time constant of one or more RC circuits to check on basic understanding
- Decide the parameters required for your device and hence the appropriate circuit design

Existing Knowledge

- Time scales for charging and discharging RC circuits
- Exponential growth and decay
- Meaning of the time constant

Capacitor Safety

Most of the capacitors available to you will be polarised. This means they can only be placed in a circuit a specific way around. Incorrect orientation can cause the capacitors to be permanently damaged, so please take care. The negative wire (side which goes to your negative bus) is black. Connecting a capacitor the wrong way round is a potential safety hazard!

Session 3

Locate the Problem

It is mentioned in the letter from the Director of Research that considerations will be made later to the 'scaling-up' of this design. The dynamo used is an important consideration here, so it is worth discussing its characteristics. You are not asked to consider the scaling explicitly.

- How does the dynamo work?
- How does the speed of rotation relate to the output voltage?

Existing Knowledge

- Faraday's Law (see Tipler)
- Design of a dynamo.

Suggested Experimental Method

Hint: Examine an oscilloscope (or Picoscope data-logger) trace of the output.

Session 4

Locate the Problem

Calibrate the output of the dynamo to the wind speed (which is different to the rotation speed, as the fan has inertia, friction, a set angle of attack, etc). What kind of relationship is it?

- If we assume that it is of the form $Voltage \propto (WindSpeed)^{\alpha}$, what is α?

- An anemometer is provided for measurement of the wind speed. There are three to be shared so will have the anemometer for only a short time. You need to be clear about how you will use it.
- Design, build and test the complete circuit.

Issues

Measurements can be made using the anemometer (for wind speed) and a multi-meter or oscilloscope connected to the dynamo (for output voltage).

The care at which these readings are taken, and the way the data is treated, is a key issue.

Supplementary Information

Oscilloscopes and data loggers:

These two devices can, to a large extent, be used interchangeably. Both can be used to measure electric potential. Care must be taken to connect the positive and negative terminals (labelled 'CH1' and GND on the data logger) to the correct place on the breadboard (remember as voltmeter, they should be connected in parallel, over the area the potential difference is to be measured.

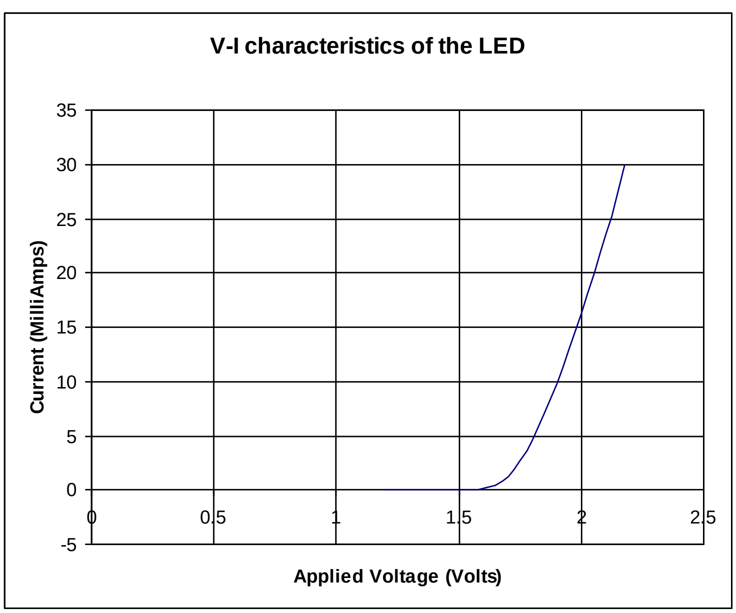
The software used with the Pico data logger is called 'PicoScope', and should have a minimum time divide per section of 200ms for the device to function correctly.

Use of the multi-meter 'resistance' setting

On this setting the multi-meter outputs a very small voltage and measures the current which flows, then calculating the resistance from Ohm's law.

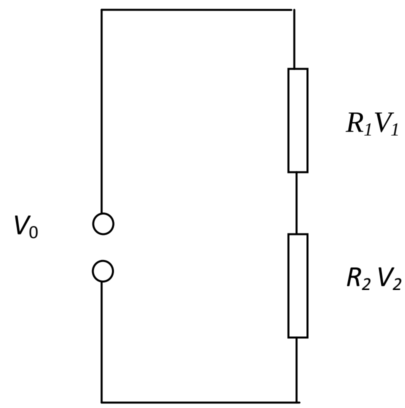
If no reading is give, the resistance can be considered infinite. This is especially relevant if it is used to measure the resistance of an LED, which is effectively infinite at small voltages. Students will have to measure potential difference and current themselves if they wish to measure the V-R characteristics of an LED, although this can be calculated from information given to students.

I-V characteristics of LEDs



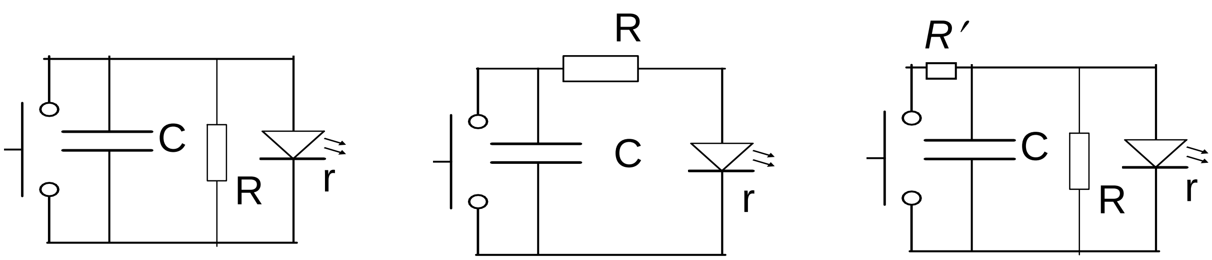
Questions for Class Discussion

1. A DC power source provides a voltage V_0. A voltage V is required to drive a device ($V < V_0$). This is to be achieved by choosing two resistors R_1 and R_2. What ratio R_1/R_2 is required? How might you decide on the absolute values?

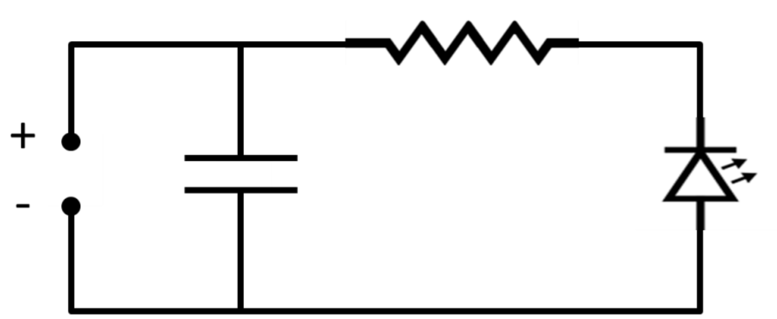


2. An uncharged capacitor has an effective resistance of zero whereas a fully charged capacitor has an infinite resistance. Can you explain this statement?

3. A fully charged capacitor, capacitance C is discharged through a resistor R. What is the time constant of circuit? What are the time constants of the circuits shown?



4. In the circuit below, how does the capacitor discharge when the dynamo stops?



How should the circuit be modified?

5. A circular coil of radius *a* rotates at an angular speed ω in a uniform magnetic field *B*. What is the output voltage? Estimate the magnetic field in the dynamo you have been using.

6. A dynamo is powered by a wind of speed *v* and provides an output voltage *V*. By estimating the work done dynamically by the wind and electrically by the dynamo derive a relation of the form $V \propto v^{\alpha}$