

The Virtual Physical Laboratory



Version 18

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www.VPLab.co.uk

*“Great are the works of the Lord;
they are pondered by all who delight in them.”
Psalms 111:2*

INTRODUCTION

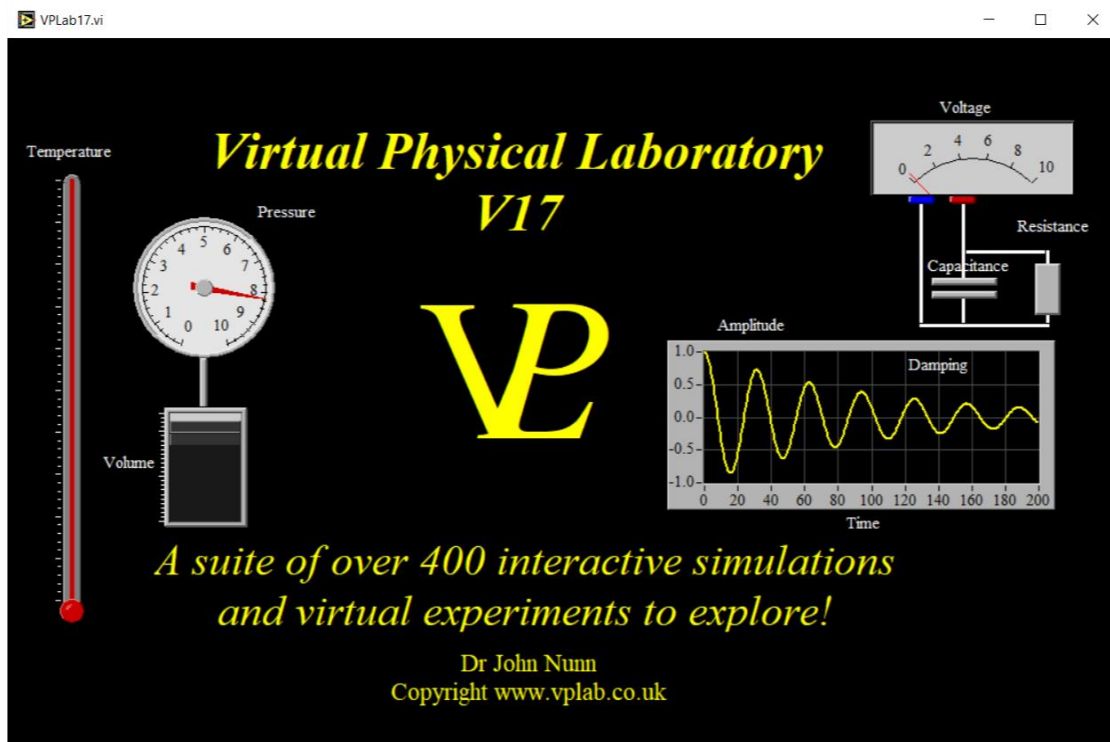
I had the privilege of teaching physics at Hebron School in Ooty in Tamil Nadu, South India between August 2000 and June 2003. It was both a privilege and a challenge, but it enriched my appreciation for my own teachers before me. It is one thing to think you understand something, it is quite another to help someone else understand it!

During my all too brief ‘teaching career’, I became convinced of the value of interactive simulations as an aid to teaching physics. The ‘experiments’ can be set up instantly, they work first time, they cannot be ‘broken’! Anyone can safely be ‘let loose’ to investigate for themselves. Every user will quickly reach the level at which they are learning something new. This will be true not only for pupils, but for teachers also; I have certainly learned a lot of physics along the way too. These simulations have become even more useful during the lock-down period brought about by the Covid-19 virus, as it has enabled teachers to demonstrate experiments by sharing their screens, and for pupils to run their own experiments from home using the VLE version of the VPLab.

Although I am no longer actively teaching pupils in school, I have spent thousands of hours over the past twenty-two years developing this resource in order to help those learning physics as well as those who are teaching it – to encourage both of them in their on-going learning of this interesting subject.

There seems to be an ever-increasing amount of science that we do not yet understand, nevertheless, I am continually fascinated by the amount of natural world around us that is understandable. It is my sincere hope that teachers and students alike will *enjoy* using this resource; that they will explore, ‘experiment’ and discover for themselves the fascination of physics.

John Nunn
September 2022



The Virtual Physical Laboratory (VPLab) illustrates and animates most of the topics taught in a modern physics curriculum. Some of the animations and virtual experiments go beyond what is required at school, but are included to stretch the more able pupils.

The Virtual Physical Laboratory is endorsed by The National Physical Laboratory, The Institute of Physics and Cambridge International Examinations. The resource is not tied to any particular syllabus, it has been used successfully in a broad range of curricula worldwide. Although the VPLab is not tied to any particular curriculum, it does include the set practical experiments set by AQA, Edexcel, OCR, and WJEC.

The simulations are arranged firstly in alphabetic order of topic, and then in alphabetic order of simulation - Except for the AQA, Edexcel, OCR and WJEC set practicals which are arranged in the order given by those boards. With each simulation I have given an indication of the level for which each simulation has been written, (Advanced or Basic) however this is merely indicative. Given the international diversity of curricula it is difficult to state comprehensively what grade a particular simulation is targeted at. I have been designated as 'Basic' and others as 'Advanced' level. 'Basic' level is broadly suitable for 12 to 16 year olds, and 'Advanced level' for 17 to 19 year olds. Not all curricula will include all the topics included in this resource, however they are included in this work as a way of covering most eventualities and also as a means to stretch and stimulate the more able pupils.

WHAT IS NEW IN VERSION 18 OF THE VPLab?

V18 has 21 additional simulations (compared to V17), bringing the total up to 439. Most of the new ones this time are all Chemistry simulations!

The 19 new chemistry simulations are grouped under four headings as follows:

Analytical:

- Chromatography
- Density of Gases
- Identifying Cations
- pH Scale
- Titration
- Water of Crystallisation

Energetics

- Electrolysis
- Enthalpy of Combustion
- Exothermic Reactions

Kinetics

- Gas Reaction
- Reaction rate Gas
- Reaction rate Precipitates
- Reactivity of Metals

Preparation

- Bunsen Burner
- Crystallisation
- Distillation
- Filtration
- Fractional Distillation
- Making Soluble Salts

The other two are the Microscope and the Telescope located in the Optics chapter

LICENSING OF THE VPLAB

With the exception of the simulations of the Diamond Synchrotron and the Neutron Source Isis, the Virtual Physical Laboratory software library is the copyright of VPLab. There are a number of possible licences that can be purchased.

Student license: For private use. Single user and single machine.

Teacher license: For public demonstrations by a teacher. Single machine.

Site License: For use within a single site educational establishment. Multiple concurrent users on networked computers, but excludes pupils personal computers.

VLE License: Using this version, the teacher can select simulations and make them available to his pupils to download from a school based fileshare. The students can then unzip the files on their own computers (typically 2Mb in size) and they can then run them for a period of one week. After that period has expired, that simulation will no longer run. The VLE version of the VPLab needs to be purchased separately.

For further details please visit the website www.vplab.co.uk. For any enquiries please email john.nunn@vplab.co.uk.

INSTALLING THE VIRTUAL PHYSICAL LABORATORY

There are a number of different ways in which you may have received the Virtual Physical Laboratory. It may come as a CD ROM or as a download from a web server.

If you are installing from a CD ROM, simply follow the instructions given on the screen, and if you accept the default options, the software will install itself in C:\program files\Virtual Physical Laboratory. It will also create a shortcut from the start menu under programs called VPLab.

If you received the Software via a download, it will normally download as a compressed or 'zipped' folder. The first step must be to 'unzip' it. Once this is done, copy the entire contents to a folder of your choice. The top level directory contains a n executable file called VPLab16.exe. Double clicking this executable opens up the program and runs it. You can also create a shortcut and place it on your desk top.

It is important that you preserve the directory structure of the Virtual Physical Laboratory, otherwise the individual simulations will not be found by the top level program.

When a school site licence has been purchased, it is possible to install the software installing the software on a server so that it can be accessed by multiple users. An easy alternative is to place the Virtual Physical Laboratory folder on a shared drive which networked computers can access. In this way any number of users can access the resource at the same time.

CUSTOMISING THE VIRTUAL PHYSICAL LABORATORY

Version 16 of Virtual Physical Laboratory has 401 simulations, and it is easy to lose the ones you are interested in! It is possible to customise the content of the VPLab to make it easier for you to find your way around.

There are two ways in which you may customise your content: Guided and Manual.

Guided method to populate My VPLab

"My VPLab.exe" was written to enable you to keep track of the simulations you want to use.

A - Run My VPLab.exe by double clicking on it.

B - Once it opens up you have the option to "Search whole VPLab Content" or "Search my Customised Content" using the button at the bottom of the screen.

Note: The first time you run My VPLab it will warn you that "You have not yet made any folders in "My VPLab" Search whole VPLab content instead.

C – Press the "Search whole VPLab Content", and the familiar chapter buttons will appear.

D – Search around for the simulation you want to use, and run it.

E - When you close it, you will see a pop-up box asking “Do you want to copy this last simulation into My VPLab”. If you answer “No” the top level program will return to your last selected chapter. If you answer “Yes” a new window will open up.

F – Initially you will need to create a new folder by pressing the “Create an New Folder” button at the bottom of the screen.

G – A small field will appear for you to enter the name of the folder you want to create. (e.g. Year 11 Term 1). Enter the text and press the “Make it” button. The folder will then appear on the vertical list above.

H – Click in the little tick box to the right of the folder name where you want to save the simulation and press the “save it here” button. (you can only save the simulation into one folder at a time).

I – Press the red “Stop or cancel Last” button to exit from that window and return to the chapter you selected.

J – Press the green “Back” button to return to the top level program with all the chapter buttons.

K – Press the “Search My Customised Content” at the bottom of the screen, and now a button with the folder you have just created should appear (e.g. Year 11 Term 1).

L – Press the new button and it should open up a new window showing its contents (perhaps just the last simulation that you have just placed in to it.)

To add more simulations to this folder, or to create new folders to populate, repeat steps B to L above.

Manual Method to Customise My VPLab.

It is also possible to create your customised sub-folders using your windows explorer. The important thing is to remember to COPY and paste (NOT cut and paste!) otherwise you will gradually start to lose the simulations available from the entire content of the VPLab.

If you have many files you want to move into the customised content directory the manual method is much quicker.

A - In the top level directory of the Virtual Physical Laboratory (where “VPLab8.exe” and “My VPLab.exe” are located), create a new folder called “My VPLab” (if it does not already exist).

B – Inside that folder (“My VPLab”), create a new folder (e.g. “Year 12 Heat”).

C – Open this folder (e.g. Year 12 Heat).

D – The virtual Physical Laboratory in another window.

E – Open the folder containing the chapter you are wanting to draw from (e.g. Heat)

F – COPY the simulation you want and PASTE it into your new folder (e.g. “Year 12 Heat”). Copy as many simulations as you wish into your new folder.

G – IMPORTANT: Make sure you also copy “lvrt.dll” and “lvsound.dll” into your new folder. These two dynamic link files can be found in every chapter folder, and also in the top level directory of the VPLab. (You only need to do this the first time you are populating your new folder).

H – Create as many folders in the “My VPLab” folder, but note that you should not create sub folders within your new folders. The folders may only be one level deep; deeper sub-folders will not be searched by “My VPLab.exe”.

It is possible to use both methods (the guided and the manual) to populate your customised content folders.

After you have finished customising your content, run “My VPLab.exe” to verify that the files are in the places you wanted them to be.

HINTS ON USING THE VIRTUAL PHYSICAL LABORATORY

This section addresses some of the most frequent questions arising out of the use of the Virtual Physical Laboratory in schools and colleges.

1 – Colours of graphs.

The colour red does not project very well, especially narrow red lines on a black background. The solution offered here will work in most cases (but not all).

To change the colour of a line on a graph, right click somewhere inside the graph and select 'show' and then 'legend' (some graphs already have the legend showing). A box near the top right hand corner of the graph will appear. Right click inside it, and you will be able to select 'colour'. A colour palette will appear. Select your preferred colour and it will change the plot accordingly. You can then hide the legend box again by right clicking somewhere inside the graph and selecting 'show' and selecting 'legend' again. Your change will be a temporary one; it will be lost as soon as you quit the simulation.

Changes of colour may also be advisable in some simulations in order to make things easier for colour blind pupils.

Notice also that right clicking on the legend also offers the possibility of changing the 'linewidth'. This may be a useful change to visually impaired students or where the projection is particularly poor.

2 - Re-scaling graphs, gauges, dials, knobs and sliders.

If a graph, gauge, dial, knob or slider goes out of range, or if you want to change the range in order to improve resolution, left-click and drag over the number at the top (or bottom) of the scale and type the new value you would like to have. The scale should automatically adjust to the new value. Your change will be a temporary one, it will be lost as soon as you quit the simulation.

If you want a graph to automatically re-scale, right click somewhere inside the graph and select 'AutoScale X' or 'AutoScale Y'

3 – Using just one or two simulations without installing the whole package. Simulations can be run independently without recourse to the top level library.

All the files which make up the Virtual Physical Laboratory are contained in a folder on the hard drive (normally in c:\program files\virtual physical laboratory). They are grouped by the same chapter divisions as shown in the top level program of VPLab.

Create a new directory with a name of your choice using windows explorer. It can be created anywhere on your computer, including on a USB memory stick, or a shared folder on a network.

Two dynamic link libraries are needed for this to work. 'lvrt.dll' (normally located in c:\program files\virtual physical laboratory) and 'lvsound.dll' (normally located in c:\program files\virtual physical laboratory\sound\data) will need to be copied (not cut

& pasted or dragged) into your new directory. Now copy (not cut & paste, and not drag) any of the simulations you want into your new folder.

These simulations will now run on any machine supporting windows 95 onwards, without needing the full installation. If using a USB memory stick, it can be transported to any other computer, and the simulations can be made to run simply by using windows explorer and double clicking on any of the '*.exe' files that you have selected to copy.

4 – Printing diagrams from the VPLab simulations.

The reason the majority of the VPLab screens are black is that it is much quicker to refresh the screen, and the graphics side of the simulations can run more smoothly. If you want to print part of a screen, the semi-satisfactory way to do this is as follows:

Press “Shift-Print Screen”, and then open Microsoft Paintbrush (Normally “Start-Programs-Accessories-Paint”). Now press “Ctrl V” (or right click and select ‘paste’). The entire screen should have dumped into the Paint Brush window. Click on the select rectangle button of paintbrush to box the part of the image you want. While it is still boxed, click on the ‘Image’ button at the top of the Paint Brush window and select ‘invert colours’ All the black should have turned to white, and all the colours are unrecognisable! This might be good enough for your purposes, but if you want to recover the original colours carry out the next step.

Now click on the ‘fill with colour’ button on the left hand side of the Paint Brush Screen (it looks like a bucket of paint), and select the black colour at the bottom left hand side of the screen and paint all the white back to black again! Then select ‘Edit – Select all’ (or Ctrl A) and then ‘Image-invert colours’ again in order to return back to the original colours (without the black). Notice that the screen pieces contained inside hollow letters may need some special attention!

5 – Printing Text from the VPLab simulations.

Unfortunately this cannot be done satisfactorily. It was not a deliberate policy, but just the way it turned out. They can only be dumped as graphics. On the plus side, it means your pupils cannot simply cut and paste, they will need to think about what they are writing!

6 – Exporting experimental data from the VPLab simulations.

This is possible in a limited number of programs. Normally only those that actually acquire data through the audio input of the computer (e.g. AC coupled Oscilloscope the AC Transient Recorder and the Power Logger). The option of exporting simulated data has not been made available as it would not be meaningful in any real sense.

VPLab 18 SIMULATIONS

No	Chapter				
	1		Astronomy		
1		1.1.	Cavendish	1	1
2		1.2.	Cepheid Variables	1	2
3		1.3.	Gravity on Planets	1	3
4		1.4.	Day Year	1	4
5		1.5.	Hubble	1	5
6		1.6.	Kepler	1	6
7		1.7.	Lander	1	7
8		1.8.	Moon Phases	1	8
9		1.9.	Orbits	1	9
10		1.10.	Parallax	1	10
11		1.11.	Sun Earth Moon	1	11
12		1.12.	Tides	1	12
		..			
	2		Charged Particles		
		..			
13		2.1.	Cathode Ray Oscilloscope Inside	2	1
14		2.2.	Cockroft Walton	2	2
15		2.3.	Diamond Synchrotron	2	3
16		2.3.A	Electron Gun	2	3 A
17		2.3.B	Linac	2	3 B
18		2.3.C	Dipole	2	3 C
19		2.3.D	Quadrupole	2	3 D
20		2.3.E	Electromagnetic Waves from Charges	2	3 E
21		2.3.F	Residual Molecules	2	3 F
22		2.3.G	RF Cavity	2	3 G
23		2.3.H	Undulator	2	3 H
24		2.4.	ISIS Neutron Source	2	4
25		2.4.A	The Ion Source	2	4 A
26		2.4.B	The Vacuum System	2	4 B
27		2.4.C	The Linac	2	4 C
28		2.4.D	The Dipole	2	4 D
29		2.4.E	The Quadrupole	2	4 E
30		2.4.F	The Stripping Foil	2	4 F
31		2.4.G	The Synchrotron	2	4 G
32		2.4.H	The Extraction Kicker	2	4 H
33		2.4.I	The Target	2	4 I
34		2.4.J	The Instruments	2	4 J
35		2.4.K	Muons	2	4 K
36		2.5.	e/m Tube	2	5
37		2.6.	Maltese Cross	2	6

38	2.7.	Mass Spectrometer	2	7
39	2.8.	Oscilloscope	2	8
40	2.9.	Thermionic Emission	2	9
41	2.10.	Velocity Selector	2	10

3

Chemistry

Analytical

42	3.1.	Chromatography	3	1
43	3.2.	Density of Gases	3	2
44	3.3.	Identifying Cations	3	3
45	3.4.	pH Scale	3	4
46	3.5.	Titration	3	5
47	3.6.	Water of Crystallisation	3	6
48	..	Energetics		
49	3.7.	Electrolysis	3	7
50	3.8.	Enthalpy of Combustion	3	8
51	3.9.	Exothermic Reactions	3	9
52	..	Kinetics		
53	3.10.	Gas Reaction	3	10
54	3.11.	Reaction rate Gas	3	11
55	3.12.	Reaction rate Precipitates	3	12
56	3.13.	Reactivity of Metals	3	13
57	..	Preparation		
58	3.14.	Bunsen Burner	3	14
59	3.15.	Crystallisation	3	15
60	3.16.	Distillation	3	16
61	3.17.	Filtration	3	17
62	3.18.	Fractional Distillation	3	18
63	3.19.	Making Soluble Salts	3	19

4

Circular Motion

64	4.1.	Angular Inertia	4	1
65	4.2.	Belt Drive	4	2
66	4.3.	Centripetal Force	4	3
67	4.4.	Circular Motion	4	4
68	4.5.	Cogs	4	5
69	4.6.	Conical Pendulum	4	6
70	4.7.	Coriolis	4	7
71	4.8.	Hub Gears	4	8
72	4.9.	Rolling Slope	4	9
73	4.10.	Rotational Energy	4	10
74	4.11.	Worm Screw	4	11

5

Communications

75	5.1.	Digital Image Grey	5	1	
76	5.2.	Digitising	5	2	
77	5.3.	Fourier	5	3	
78	5.4.	Modulation	5	4	
79	5.5.	Noise in transmission	5	5	
80	5.6.	Sampling	5	6	
81	5.7.	Transmitting Images	5	7	
	..				
	6	.. Dynamics			
82	6.1.	Bullet Speed	6	1	
83	6.2.	Loop the Loop	6	2	
84	6.3.	Momentum	6	3	
85	6.4.	Power	6	4	
86	6.5.	Roller Coaster	6	5	
87	6.6.	Stopping Distance	6	6	
88	6.7.	Work	6	7	
89	6.8.	2D Collisions	6	8	
	..				
	7	.. Electricity AC			
90	7.1.	AC Power	7	1	
91	7.2.	AC Rectification	7	2	
92	7.3.	Capacitor Reactance	7	3	
93	7.4.	Generator	7	4	
94	7.5.	Inductor Reactance	7	5	
95	7.6.	LCR Reactance	7	6	
96	7.7.	Power Distribution	7	7	
97	7.8.	Three Phase Supply	7	8	
98	7.9.	Transformer	7	9	
	..				
	8	.. Electricity DC			
	8.1.	Circuits	8	1	
99	8.1.A	Parallel	8	1	A
100	8.1.B	Series	8	1	B
101	8.2.	Decomposing Water	8	2	
102	8.3.	Electrolysis	8	3	
103	8.4.	Electroplating	8	4	
104	8.5.	EMF and Internal Resistance	8	5	
105	8.6.	Explaining Electricity	8	6	
106	8.7.	I V Characteristics	8	7	
107	8.8.	I V of Lamp and Wire	8	8	
108	8.9.	Load Matching	8	9	
109	8.10.	Potential Divider	8	10	
110	8.11.	Potentiometer	8	11	
111	8.13.	Resistivity	8	13	

112	8.14.	Resistance and Temperature	8	14
113	8.15.	Strain Gauge	8	15
114	8.16.	Unbalanced Wheatstone	8	16
115	8.12.	Wire Resistances	8	12
116	8.17.	Wheatstone	8	17
	..			
	9	.. Electromagnetism		
117	9.1.	AC Generator	9	1
118	9.2.	Bell	9	2
119	9.3.	Coil Transformer	9	3
120	9.4.	Current Balance	9	4
121	9.5.	DC Motor and Generator	9	5
122	9.6.	Dynamo	9	6
123	9.7.	Eddy Current Pendulum	9	7
124	9.8.	Electromagnet	9	8
125	9.9.	Hall Probe	9	9
126	9.10.	Hysteresis	9	10
127	9.11.	Induction	9	11
128	9.12.	LVDT	9	12
129	9.13.	Magnetic Fields	9	13
130	9.14.	Magnets	9	14
131	9.15.	Moving Coil	9	15
132	9.16.	Switched Mode Transformer	9	16
	..			
	10	.. Electronics		
133	10.1.	Capacitor	10	1
134	10.2.	Capacitor Combinations	10	2
135	10.3.	Diodes	10	3
136	10.4.	Energy in Capacitors	10	4
137	10.5.	High Pass Filter	10	5
138	10.6.	Light Dependent Resistor	10	6
139	10.7.	Light Emitting Diodes	10	7
140	10.8.	Logic Gates	10	8
141	10.9.	Low Pass Filter	10	9
142	10.10.	Operational Amplifiers	10	10
143	10.11.A	Voltage Comparator	10	11 A
144	10.11.B	Non Inverting Amplifier	10	11 B
145	10.11.C	Inverting Amplifier	10	11 C
146	10.11.D	Adder	10	11 D
147	10.11.E	Difference Amplifier	10	11 E
148	10.11.F	Differentiating Amplifier	10	11 F
149	10.11.G	Integrator	10	11 G
150	10.11.H	Digital to Analogue	10	11 H
151	10.11.I	Subtractor	10	11 I

152	10.12.	Oscillator	10	12	
153	10.13.	Photodiodes	10	13	
154	10.14.	Semiconductors	10	14	
155	10.15.	Thermistor	10	15	
156	10.16.A	Transistor	10	16	A
157	10.16.B	Input Characteristics	10	16	B
158	10.16.C	Output Characteristics	10	16	C
159	10.16.D	Current Transfer Characteristics	10	16	D
160	10.16.E	The Transistor as an Audio Amplifier	10	16	E
161	10.17.	Zener Diodes	10	17	
	..				
	11	.. Electrostatics			
162	11.1.	Electrometer	11	1	
163	11.2.	Electrostatic Induction	11	2	
164	11.3.	Electrostatic Pendulum	11	3	
165	11.4.	Coulomb's Law	11	4	
166	11.5.	Van Der Graaf	11	5	
	..				
	12	.. Energy			
167	12.1.A	Coal	12	1	A
168	12.2.B	Oil	12	2	B
169	12.3.	Domestic Solar Heating	12	3	
170	12.4.	Gas	12	4	
171	12.5.	Geothermal	12	5	
172	12.6.	Hydroelectric Power	12	6	
173	12.7.	Nuclear Power	12	7	
174	12.8.	Solar Power	12	8	
175	12.9.	Tidal Barrage	12	9	
176	12.10.	Wave Energy	12	10	
177	12.11.	Wind Power	12	11	
	..				
	13	.. Fluids			
178	13.1.	Bernoulli	13	1	
179	13.2.	Bubbles	13	2	
180	13.3.	Capillarity	13	3	
181	13.4.	Contact Angle	13	4	
182	13.5.	Hydrostatics	13	5	
183	13.6.	River	13	6	
184	13.7.	Surface Tension	13	7	
185	13.8.	Measure Surface Tension	13	8	
186	13.9.	Viscosity	13	9	
	..				
	14	.. Forces			
187	14.1.	Balance	14	1	

188	14.2.	Balanced Forces	14	2
189	14.3.	Car Forces	14	3
190	14.4.	Catenary	14	4
191	14.5.	Centre of Gravity	14	5
192	14.6.	Equilibrium	14	6
193	14.7.	Force and Acceleration	14	7
194	14.8.	Friction	14	8
195	14.9.	Hookes Law	14	9
196	14.10.	Ladder	14	10
197	14.11.	Lift	14	11
198	14.12.	Material Friction	14	12
199	14.13.	Pulleys	14	13
200	14.14.	Rotational Equilibrium	14	14
201	14.15.	Springs	14	15
202	14.16.	Tip or Slip	14	16
203	14.17.	Torques and Moments	14	17
	..			
	15	Gases		
	..			
204	15.1.	4 Stroke Engine	15	1
205	15.2.	Boyles Charles	15	2
206	15.3.	Boyles Practical	15	3
207	15.4.	Diesel Engine	15	4
208	15.5.	Diffusion	15	5
209	15.6.	Heat Pump	15	6
210	15.7.	Isothermal Adiabatic	15	7
211	15.8.	Steam Engine	15	8
212	15.9.	Stirling Engine	15	9
	..			
	16	Heat		
	..			
213	16.1.	Boiling	16	1
214	16.2.	Conduction	16	2
215	16.3.	Constant Flow	16	3
216	16.4.	Convection	16	4
217	16.5.	Cooling curves	16	5
218	16.6.	Evaporation	16	6
219	16.7.	Gas Expansion	16	7
220	16.8.	Heat and Area	16	8
221	16.9.	Heat Capacity	16	9
222	16.9.	Joule Experiment	16	9
223	16.10.	Latent Heat	16	10
224	16.11.	Liquid Expansion	16	11
225	16.12.	Melting	16	12
226	16.13.	Mixtures Method	16	13
227	16.14.	Radiation	16	14

228	16.15.	Solid Expansion	16	15
229	16.16.	Vapourisation	16	16
230	16.17.	Weather	16	17
	..			
17	..	Kinematics		
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CHAPTER 1

ASTRONOMY

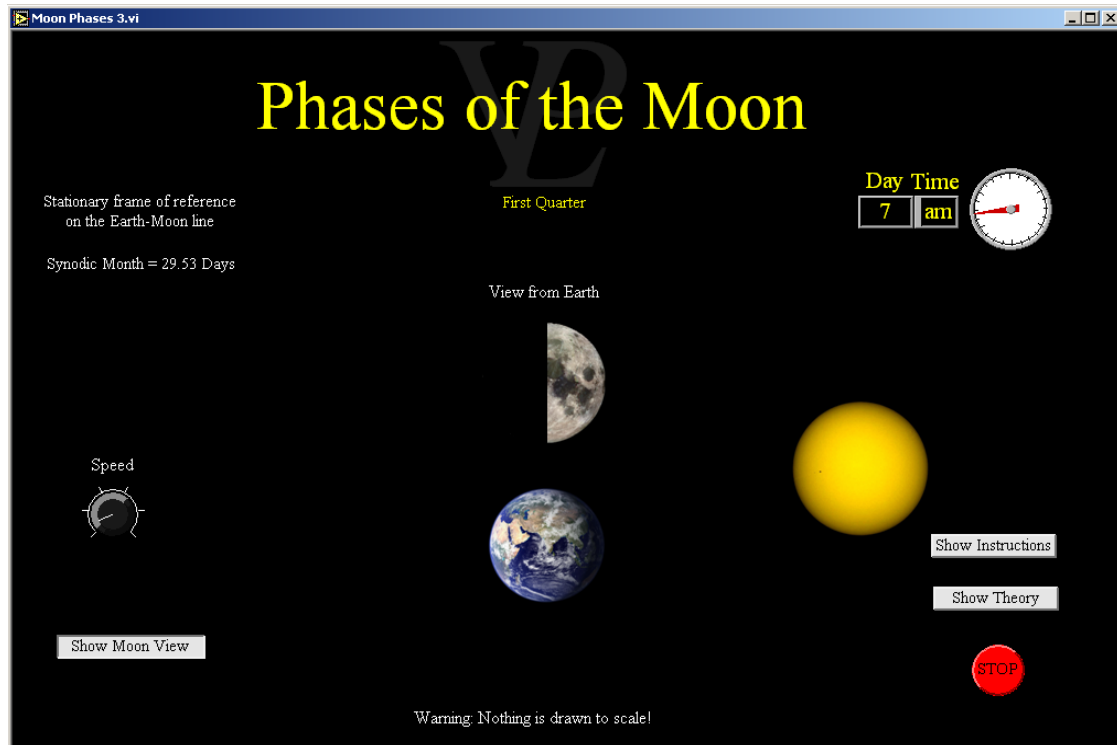


The moon looks different as the month progresses.
What makes it “change shape”?

1.8 Moon Phases

Advanced

This simulation shows how the appearance of the moon changes during the month. The user can toggle between Earth's view and a view from space.



The phases of the moon are something you have probably observed for years. Perhaps you have wondered why it looks the way it does. It is all to do with which side of the Moon the sun is at, and how the sunlight falls upon the Moon.

It is natural for an Earth observer to look upon things as if he were stationary and the Moon and Sun are rotating about him. Lunar months are not the same as calendar months. What is more, there are several different ways to define a lunar month. The two most common are:

A Synodic Month. This is what the common Earth observer would note. It is the time it takes to go from a New Moon to the next New Moon. (or from Full Moon to Full moon). It is 29.53 days long. This is the cycle that also governs the tides.

A Sidereal Month is the time taken between the Moon going past a fixed star out in space (as seen from Earth) until the next time it goes past the star. This takes slightly less time to complete, 27.32 days!

CHAPTER 2

CHARGED PARTICLES



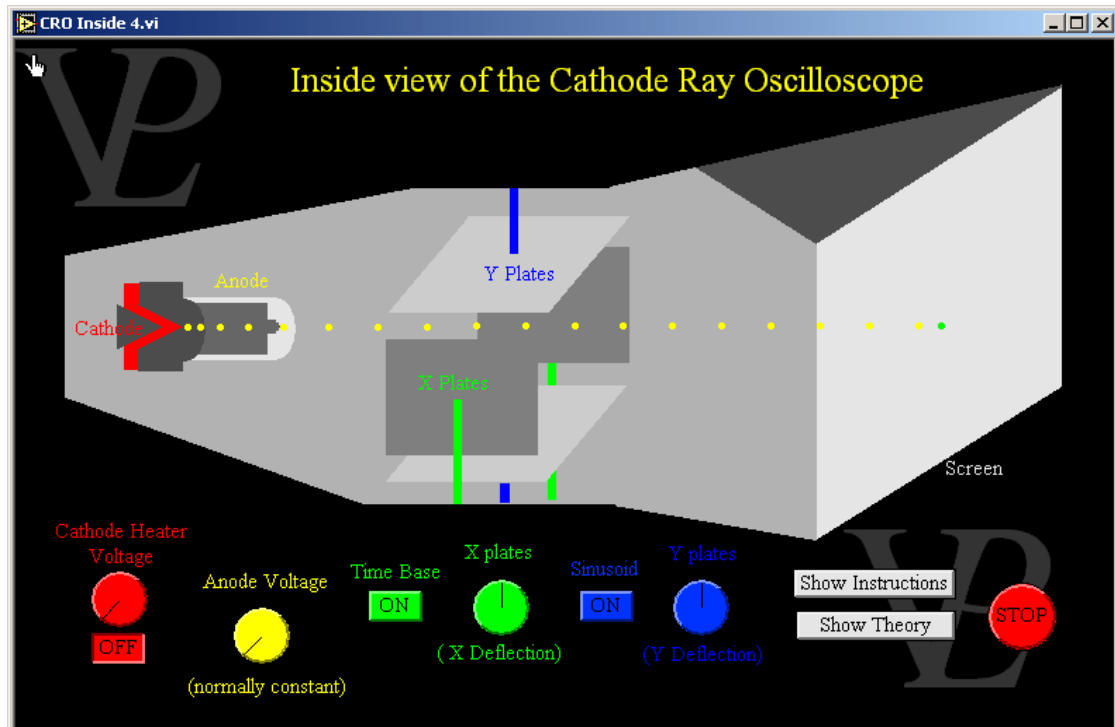
Charged particles make computer monitors glow.
How do they get there?

Charged Particles 2.1

2.1 Inside a CRO

Basic/Advanced

This simulation shows the internal workings of a cathode ray oscilloscope, including the cathode, anode, X and Y deflection plates and the time-base.



When a metal is heated sufficiently, electrons can escape from the surface. This is called thermionic emission. The hotter the metal, the more electrons will jump out of it.

Normally the electrons will simply fall back into the metal and there is no net current flowing away from the metal.

In order to get the electrons to flow away from the metal surface it is necessary to place a positively charged anode in front of it to attract them away.

In a CRT the anode has a small hole in the middle of it, and that allows the electrons to pass through. In this way an electron beam is made.

The electron beam then passes between the X and Y plates where it gets deflected one way or the other by voltages applied to them.

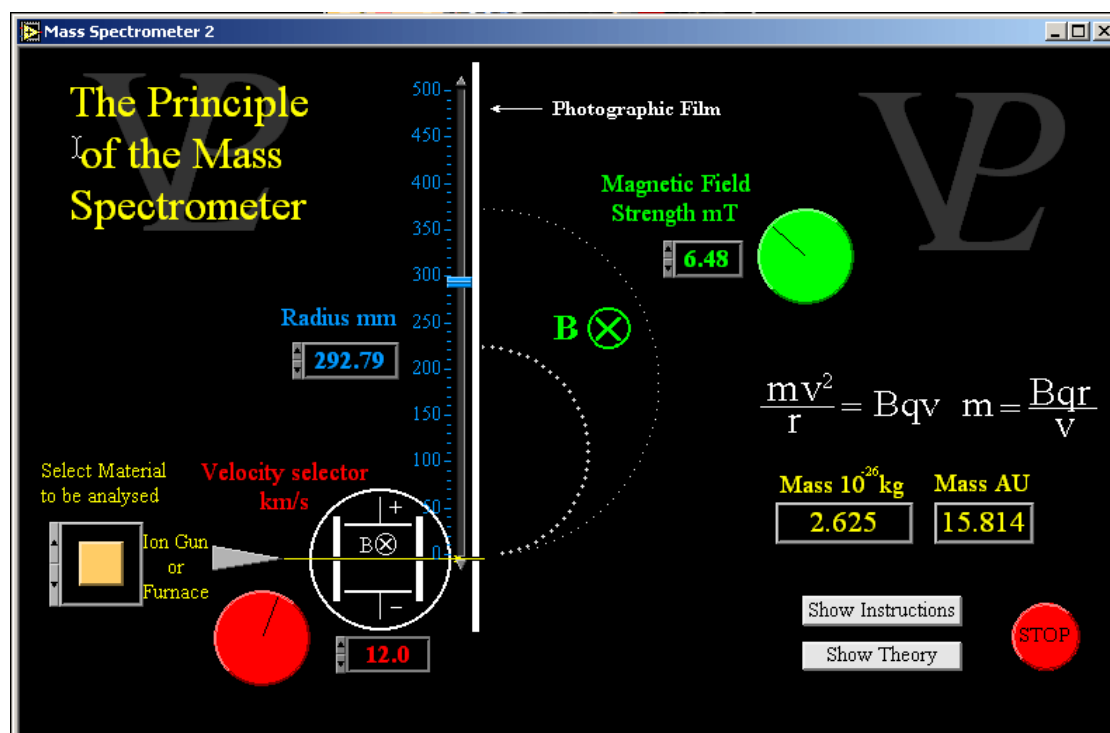
Finally the electron beam strikes the scintillating screen of the oscilloscope, where the kinetic energy of the electron gets converted into light.

Charged Particles 2.7

2.7 Mass Spectrometer

Advanced

This simulation shows the workings of a mass spectrometer, where the mass of the ions and the magnetic field strength can be varied, thus producing circular paths of different radius.



When a charged particle travels across a magnetic field it experiences a force which follows Fleming's left hand rule. The direction of the force will be perpendicular to the magnetic field and also to the direction in which the charged particle is travelling.

When any object experiences a force which is perpendicular to its velocity it will travel in a circle with the force providing the centripetal acceleration.

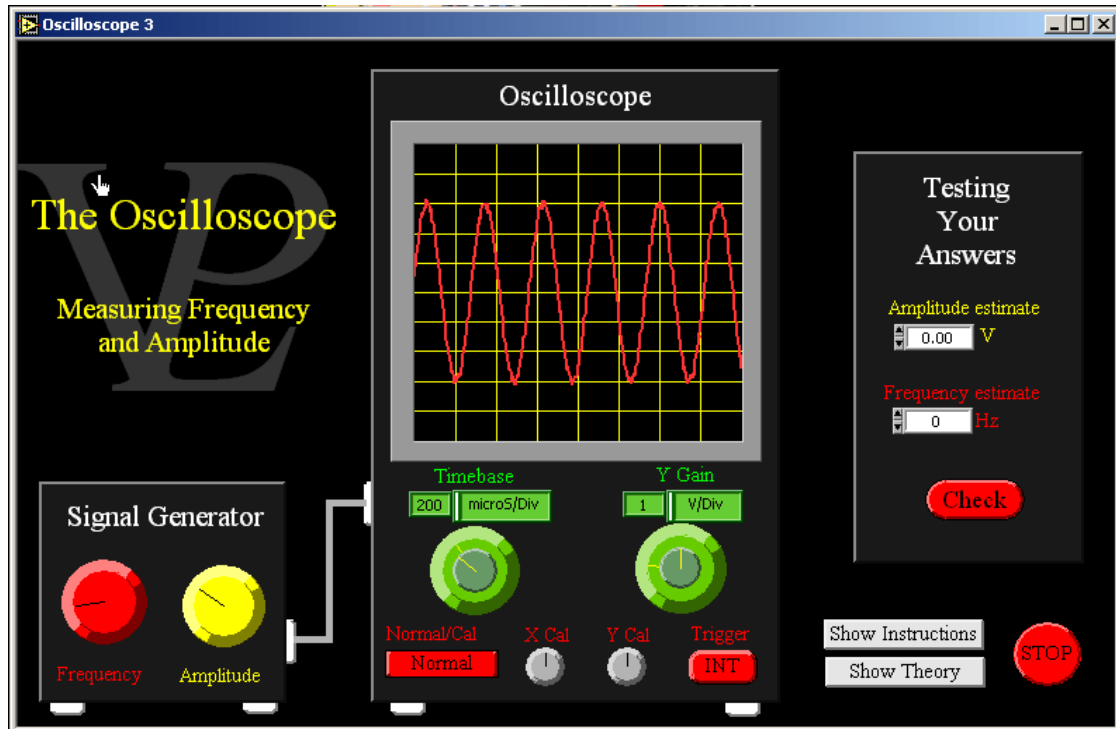
In this simulation the magnetic field (symbol B) is directed perpendicularly into the screen. The centripetal force is equal to the force due to the charge travelling through the magnetic field. Therefore $\frac{mv^2}{r} = Bqv$, where m is the mass of the particle, v is its velocity, r is the radius of its trajectory, B is the magnetic field strength and q is the electric charge on the particle. Rearranging we find that $m = \frac{Bqr}{v}$

So knowing the velocity and charge of the ion, the radius of the trajectory and the field strength it is possible to calculate the mass of the ion. This is how many isotopes were discovered.

2.8 Oscilloscope

Basic/Advanced

This simulation combines a signal generator and an oscilloscope, with variable gain and time-base so that it can be used to measure the amplitude and frequency of the signal.



The amplitude is defined as the distance between the mid point of a signal, its central axis and the maximum (or minimum). This is the same as half the peak to trough distance.

The period is the time taken to complete one cycle.

The frequency is defined as the number of cycles completed in one second. The frequency is the inverse of the period.

The Y gain shows how many Volts make up a division on the scale. Multiply this number by the number of divisions that make up the amplitude to get the amplitude in Volts.

The timebase shows the time taken for the beam to sweep one division horizontally. Count the number of divisions that make up one complete cycle and multiply it by the timebase to get the period of the signal. Take the inverse of the period to find the frequency of the signal.

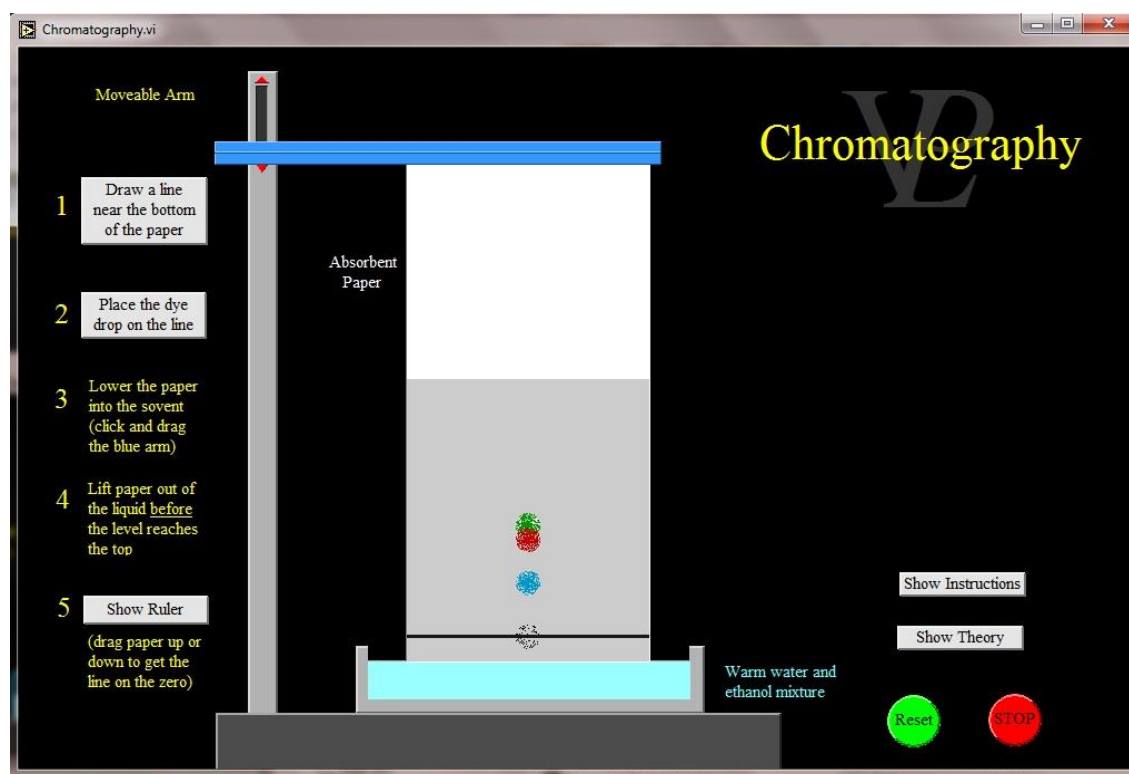
CHAPTER 3

CHEMISTRY

3.1 Chromatography

Basic

Chromatography is a useful way to separate substances based on their difference in solubility. The technique uses a Stationary Phase (the paper) and a Mobile Phase (the solvent).



When the bottom edge of the paper is lowered into the solvent, the solvent is absorbed by the paper and it starts to rise. As the solvent goes past the substance being analysed it dissolves the different compounds differently. Different substances have different attachments to the Stationary Phase and to the Mobile phase. Those more attached to the Mobile phase travel further up the paper while those more attached to the Stationary phase will move more slowly.

A pure compound will produce a single spot, a mixture of compounds will produce several spots and insoluble compounds will not travel at all. To be able to measure the differences it is necessary to record a starting point. A line is drawn in pencil (not pen) because graphite will not dissolve whereas ink will.

The mobility measured is called the R_f value which is defined as:

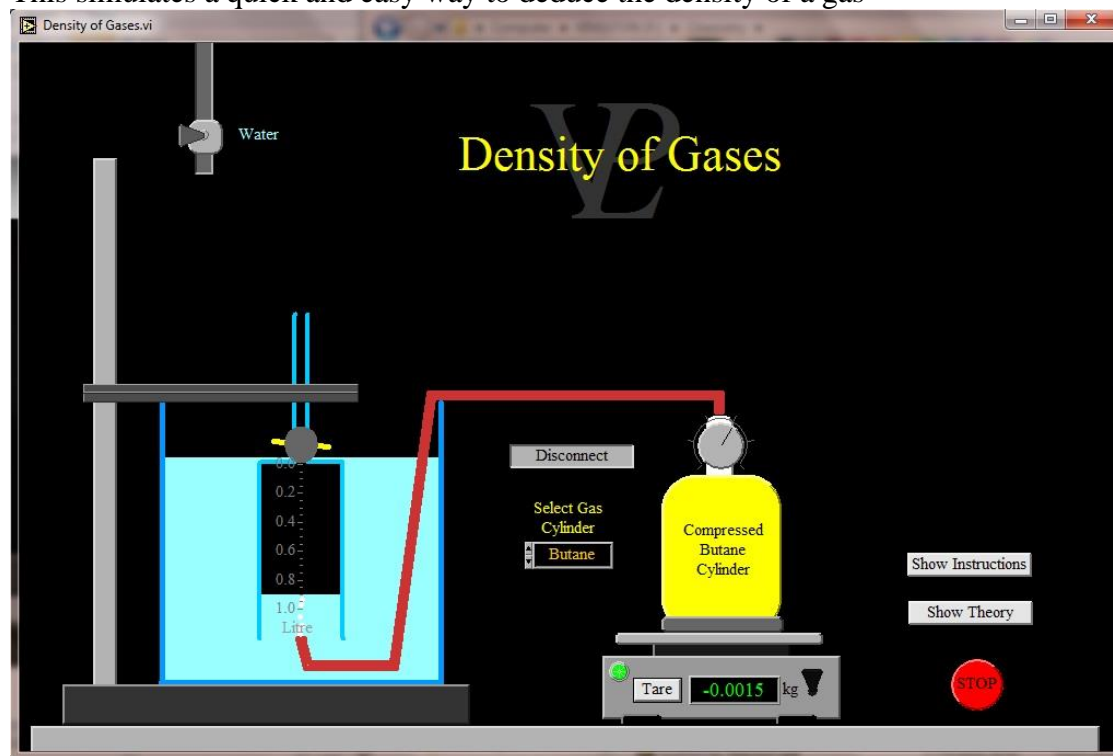
$$R_f = \frac{\text{Distance travelled by substance}}{\text{Distance travelled by solvent.}}$$

R_f values are unique to substances, but they do depend on the type of paper used and also on the solvent used, so it is important to record these details.

3.2 Density of Gases

Advanced

This simulates a quick and easy way to deduce the density of a gas



Measuring the density of a gas is a little tricky for a number of reasons:

A – The volume of gas is strongly affected by pressure

B - We cannot see a gas, so measuring its volume directly is difficult.

C - Gases are so light that the upthrust of the surrounding air (with similar density) can seriously affect the measurement.

When we allow gas to escape from a cylinder, the weight of the cylinder gradually decreases. If we can collect the gas that has escaped from the gas cylinder and measure its volume, we can calculate its density directly. Using an inverted measuring cylinder that is initially filled with water, we can measure the volume of the escaping gas by seeing how much water it displaces.

The volume of the escaped gas caught in the inverted measuring cylinder will be affected a little by the pressure exerted by the weight of the water, but its effect can be reduced by raising/lowering the inverted cylinder until the water level inside is roughly level with that of the water outside.

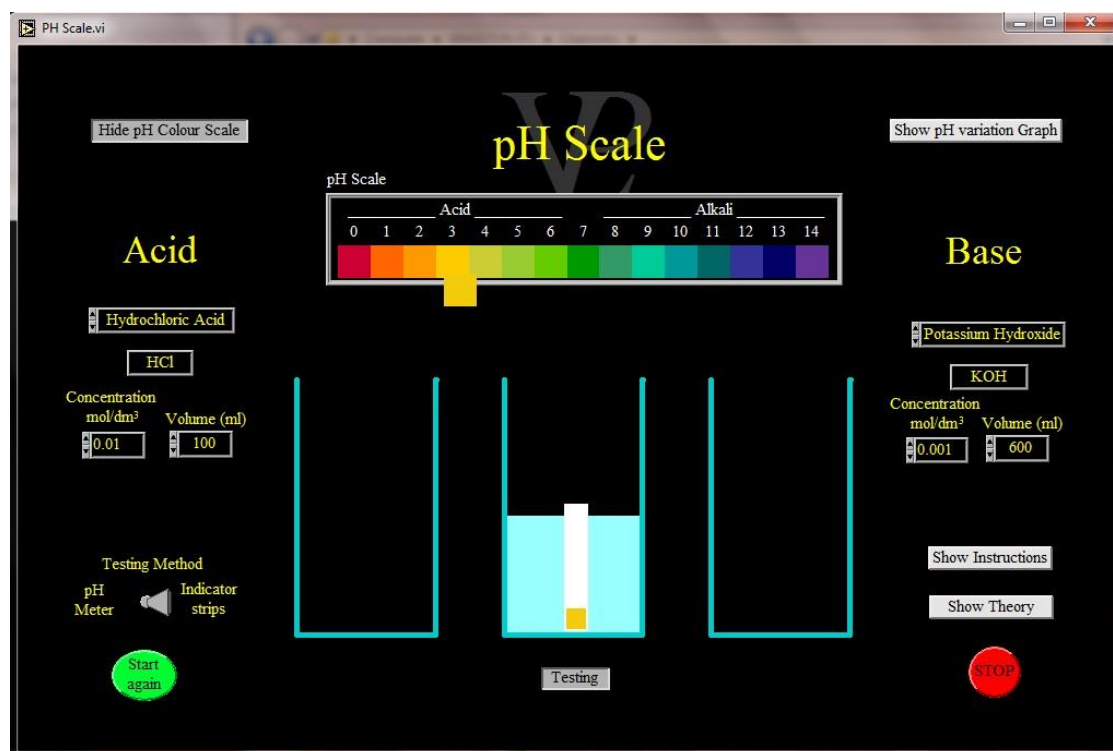
If the balance weighing the gas cylinder does not have enough decimal places, it may be necessary to measure the mass loss after five, ten or even more litres of gas have escaped.

We must always state the temperature and pressure at which the density of the gas was measured. These are often room temperature (20C, and Atmospheric pressure. Make sure the water you are using is at 20C (the air will take on the temperature of the water).

3.4 pH Scale

Basic

The pH scale is the scale on which acidity (or alkalinity) is measured. pH values below 7 indicate acidity, and those above 7 indicate alkalinity. 7 is "neutral" - like water at room temperature.



No-one is exactly sure what the "p" in pH stands for, but it is something like the "power" or "potential" of Hydrogen. The pH is a measure of the concentration of free hydrogen atoms in a solution. This can vary so greatly that to make a scale that can encompass most of the chemical solutions normally encountered it needed to be a logarithmic scale! pH is defined as $\text{pH} = -\log [\text{H}^+]$ where $[\text{H}^+]$ is the concentration of H in mol per dm. Note $1 \text{ dm}^3 = 1 \text{ litre (L)}$

The further away from 7 the pH of a solution is, the stronger the acidity or alkalinity of the solution: (pH=2 is more acid than pH=5, and pH=10 is more alkaline than pH=8).

Acids are called "monoprotic" if each molecule contributes a single H atom to the solution (diprotic if they contribute 2, triprotic if 3, etc).

Alkalinity (or how basic a solution is) depends on the concentration of free hydroxide molecules (OH^-) in the solution. Similarly bases can be "monobasic", "dibasic" etc, depending on the number of OH molecules each molecule contributes to the solution. The "Alkalinity Scale" is defined as $\text{pOH} = -\log [\text{OH}^-]$

Interestingly the product of the H concentration in solution and the concentration of OH in solution are related by a simple equation: $[\text{H}^+] \times [\text{OH}^-] = 10^{-14}$ so $\text{pH} + \text{pOH} = 14$.

CHAPTER 4

CIRCULAR MOTION



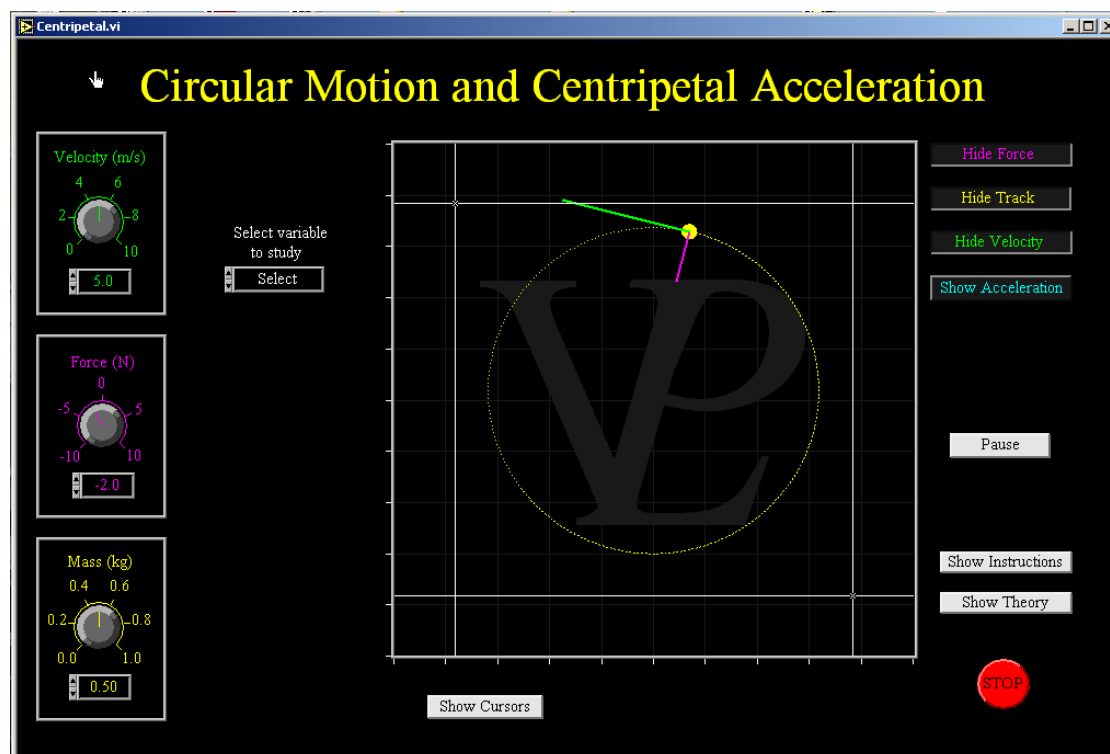
Old record players turn at constant angular velocity.
Is the tangential velocity constant too?

Circular Motion 4.3

4.3 Centripetal Acceleration

Advanced

This simulation allows the user to adjust the mass and velocity of a puck and then apply a centripetal force and see how its trajectory is affected. Each of the variables can be changed during motion, and a study can be made of how each of these affects the radius of the trajectory. Data can be stored and a graph will be displayed.



Whenever an object which is travelling at constant speed is acted upon by a force which is always perpendicular to its instantaneous velocity, the motion that follows will be circular.

This force will be causing the object to accelerate (to change its velocity) but because the acceleration is always perpendicular to the velocity, it only changes the direction of the velocity, not its speed. This is an important concept. The object is continually accelerating towards the centre of the circle, but never gets any closer to it!

The force needed to keep the object travelling in a circular path is called "Centripetal Force". Its relationship to the velocity, mass and radius of trajectory is given by:

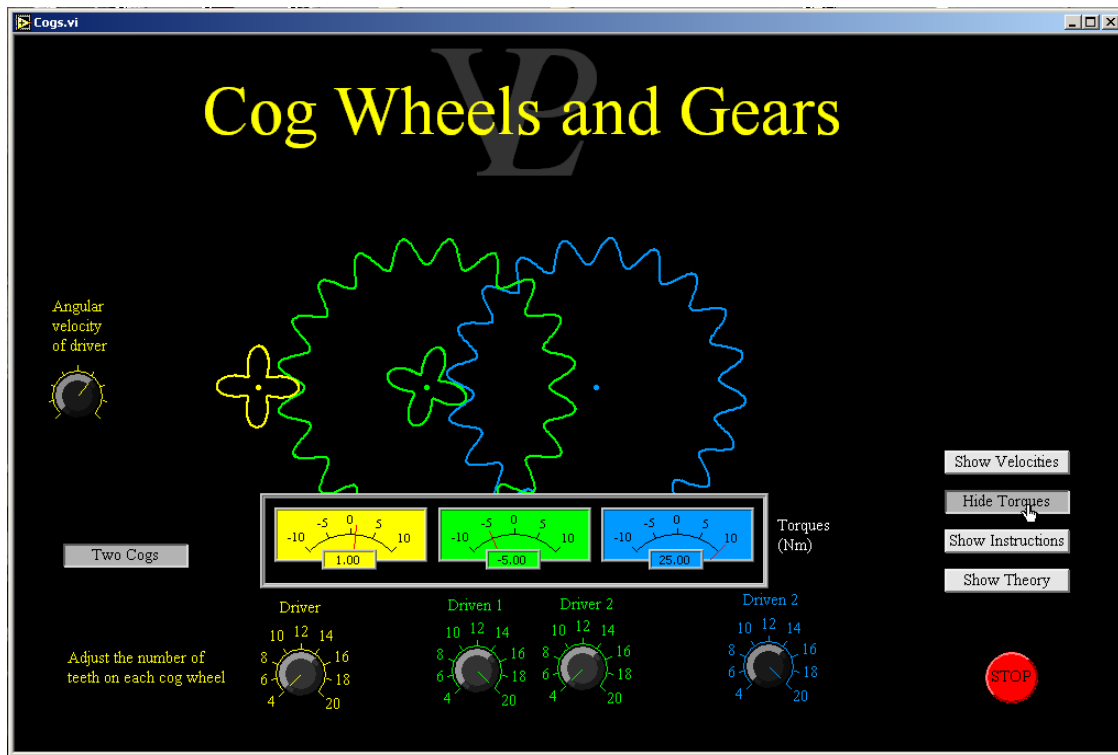
$$F = \frac{mv^2}{r}$$

The centripetal force needed to keep satellites in orbit is provided by gravitational attraction to the Earth. When planets travel in such a way that their velocity is not always perfectly perpendicular to the gravitational attraction to the Sun, the orbits are not circular but elliptical; neither the velocity nor the radius is constant.

4.5 Cogs

Basic/Advanced

This simulation shows a system of two or four meshing cog wheels and shows how the ratios of the angular velocities and of the torques depend on the ratio of the number of teeth on the cogs.



Cog wheels are used inside many machines from engines to clocks. Their purpose is to increase or decrease the angular velocity of the driven wheels. For cogs to engage or mesh properly they must have teeth of equal sizes.

The ratio of the angular velocities of two meshing cog wheels is inversely proportional to the ratio of their number of teeth.

$$\frac{V_1}{V} = \frac{N_2}{N_1}$$

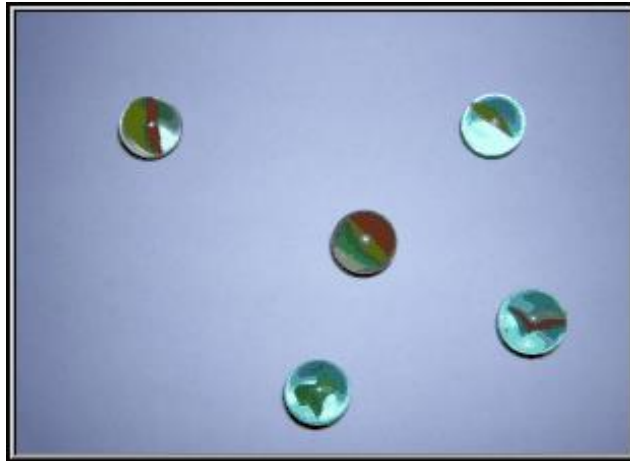
A consequence of changing the angular velocity is that the torque also changes. As a rule, when the angular velocity of the driven cog is greater, its torque is smaller. The ratio of the torques is directly proportional to the ratio of the number of teeth.

$$\frac{T_1}{T} = \frac{N_1}{N_2}$$

When there is a train of cogs all driven by the first one, the velocity and torque of the final one can be calculated from the product of the ratios of the meshing cogs.

CHAPTER 6

DYNAMICS

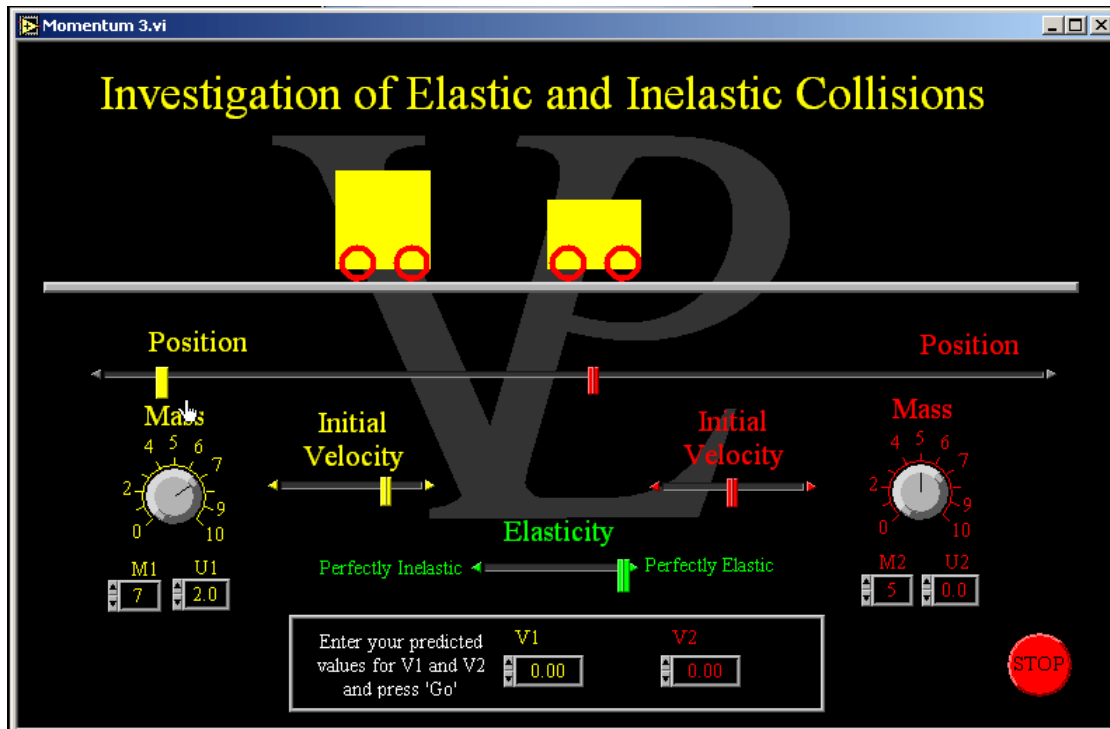


Marbles are nearly out of fashion now.
What do they have to do with dynamics?

6.3 Momentum

Advanced

In this simulation trolleys of variable mass are made to collide with each other. Investigate elastic and inelastic collisions. Predict the final velocities of the trolleys and see if you get them right!



Momentum is defined as the product of the mass and the velocity of an object. The special thing about momentum is that it is a quantity which is always conserved unless outside forces are acting upon a system. So in a collision between two objects we can say Initial momentum = Final Momentum.

Or expressed as an equation $(M_1 U_1) + (M_2 U_2) = (M_1 V_1) + (M_2 V_2)$ (1)

On the other hand kinetic energy may or may not be conserved. We speak of two types of collision:

- 1 - Elastic collisions in which all the kinetic energy is conserved. It may be passed from one body to another, but it is not lost.
- 2 - Inelastic collisions, where not all the kinetic energy is conserved. That does not mean that it is all lost, but just that it is not all conserved.

For an elastic collision we say K.E. before collision = K.E. After collision.

Or in equation form $(\frac{1}{2} M_1 U_1^2) + (\frac{1}{2} M_2 U_2^2) = (\frac{1}{2} M_1 V_1^2) + (\frac{1}{2} M_2 V_2^2)$ (2)

If we combine equations (1) and (2), we can obtain a more useful result which tells us that for an elastic collision,

relative velocity of approach = - (the relative velocity of separation)

Or in equation form $U_1 - U_2 = -(V_1 - V_2)$ (3)

This result is very useful, because it allows us to work out if a collision was elastic or not. If the relative velocities before and after the collision don't match, it was not an elastic collision (energy was lost).

CHAPTER 7

ELECTRICITY AC

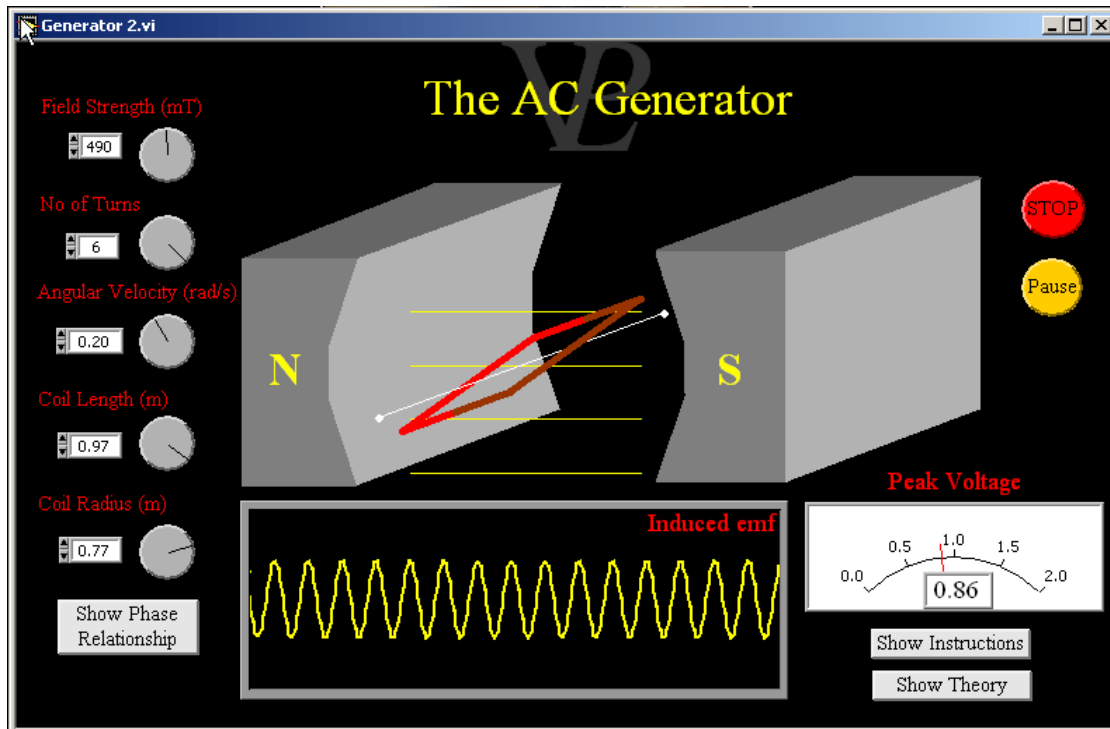


AC electricity has 101 uses around the house.
What exactly is AC?

7.1 AC Generator

BASIC/Advanced

This simulation shows how alternating currents are induced in a rotating coil. The coil parameters can be varied in order to investigate the effect. The phase relationship between the coil orientation and the induced emf are also shown.



Michael Faraday, sometimes known as the 'Father of Electricity', discovered that whenever a conductor cuts across magnetic field lines it causes a 'electromagnetic force' (known as an emf) to be induced across the ends of that conductor. The unit of emf is Volts, so it is also correct to describe the emf as an induced voltage.

The size of the voltage induced depends on the strength of the magnetic field, the length of the conductor cutting across the field and speed with which the wire cuts through. If additional wires are connected in series with the first one, that can also increase the induced voltage.

The AC generator is the way in which almost all electricity is produced today. Water or steam driven turbines are used to turn coils inside large electromagnets.

Although the magnetic flux through the coil is maximum when the plane of the coil is perpendicular to the magnetic field, the rate of change of flux at that position is a minimum so the induced emf is also minimum

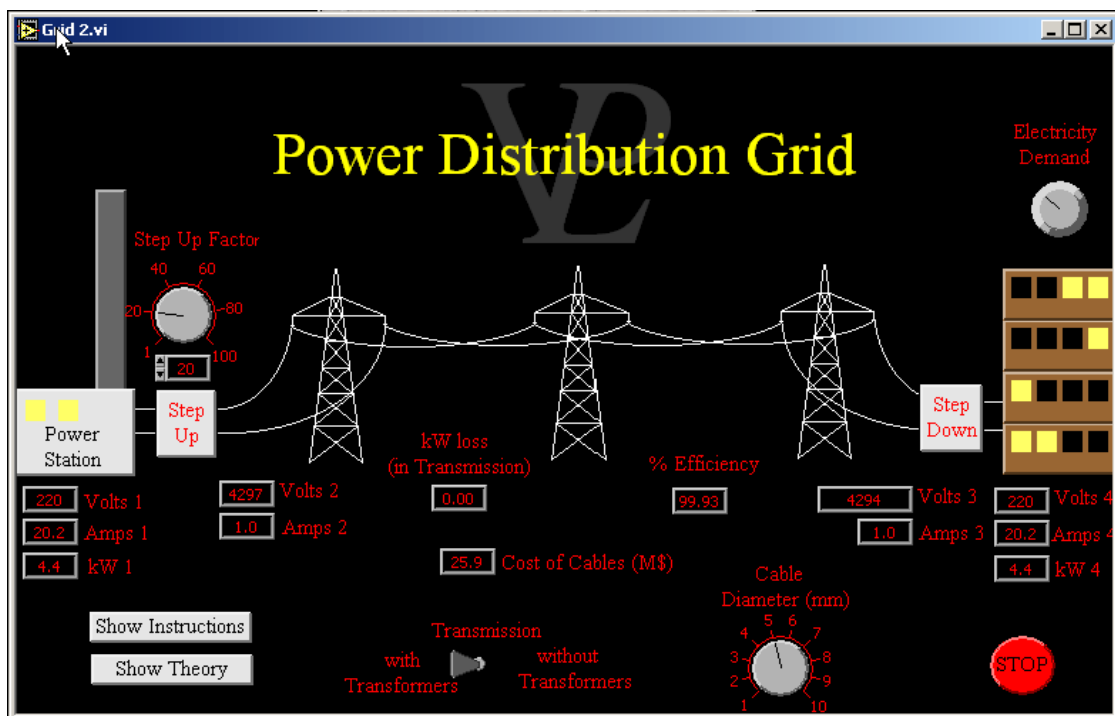
The magnetic flux through the coil is minimum when the plane of the coil is parallel to the magnetic field, however the rate of change of flux at that position is a maximum. Since the induced emf is equal to the rate of change of flux linkage, the emf (and consequent current) is maximum when the plane of the coil is parallel to the magnetic field.

Electricity AC 7.7

7.7 Power Distribution

Advanced

This simulation illustrates why it is necessary to distribute electrical power at high voltage. Power losses are shown and current limits due to the cable diameter are imposed.



Power distribution is an important practical and economic challenge.

Without using transformers to step up the voltage (and step down transformers to stabilise the voltage near the consumers) the potential at the delivery point drops as the customers load the grid with their demand. Above a particular demand (or loading), the power delivered actually starts to fall.

You can improve matters a little by increasing the diameter of the cables, but this makes the cables more expensive, and the efficiency of transmission is still poor (power wasted as heat in the cables).

Using step-up and step-down transformers helps to reduce the energy wasted and keeps the cost of the transmission wires down. National grids go as high as 400,000 Volts.

High voltage transmission is used for the following reasons:

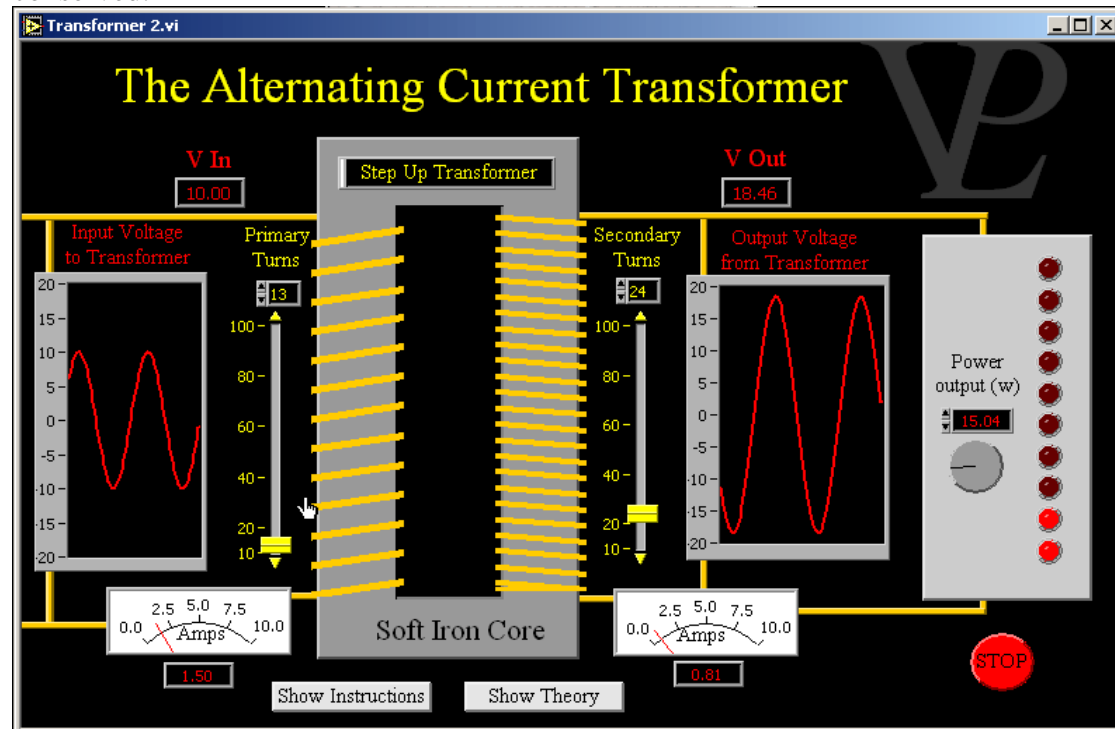
- 1 - It makes transmission more efficient
- 2 - It makes it possible to use thinner cables (cheaper cables and pylons)
- 3 - It makes larger power delivery possible.

Electricity AC 7.9

7.9 Transformer

Advanced

This simulation illustrates a simple transformer where the number of turns in the primary and secondary may be adjusted independently. Graphs show the input and output AC voltages, and dials monitor (V_{in} , I_{in}) and (V_{out} , I_{out}) showing power is conserved.



The primary coil produces a varying magnetic field through the soft iron core of the transformer. The changing magnetic field induces an electro-motive force in the secondary coil. If the number of turns in the secondary coil is greater than the number of turns in the primary coil, the induced emf will be larger than the input voltage to the transformer. This is called a step-up transformer. If the number of turns in the secondary coil is smaller than that in the primary, the emf will be smaller. This is known as a step-down transformer.

The ratio of the voltages will be equal to the ratio of the turns of the two coils.

$$\frac{V_{out}}{V_{in}} = \frac{N_{out}}{N_{in}}$$

A transformer does not create energy from nowhere. The increase in voltage is achieved at the expense of the current. If the output voltage is greater, the output current will be smaller. Large transformers can be very efficient and in an idealised situation where there is no power loss we can say that Power In = Power out

$$V_{in} I_{in} = V_{out} I_{out} \quad \text{Therefore} \quad \frac{I_{out}}{I_{in}} = \frac{N_{in}}{N_{out}}$$

CHAPTER 8

ELECTRICITY DC



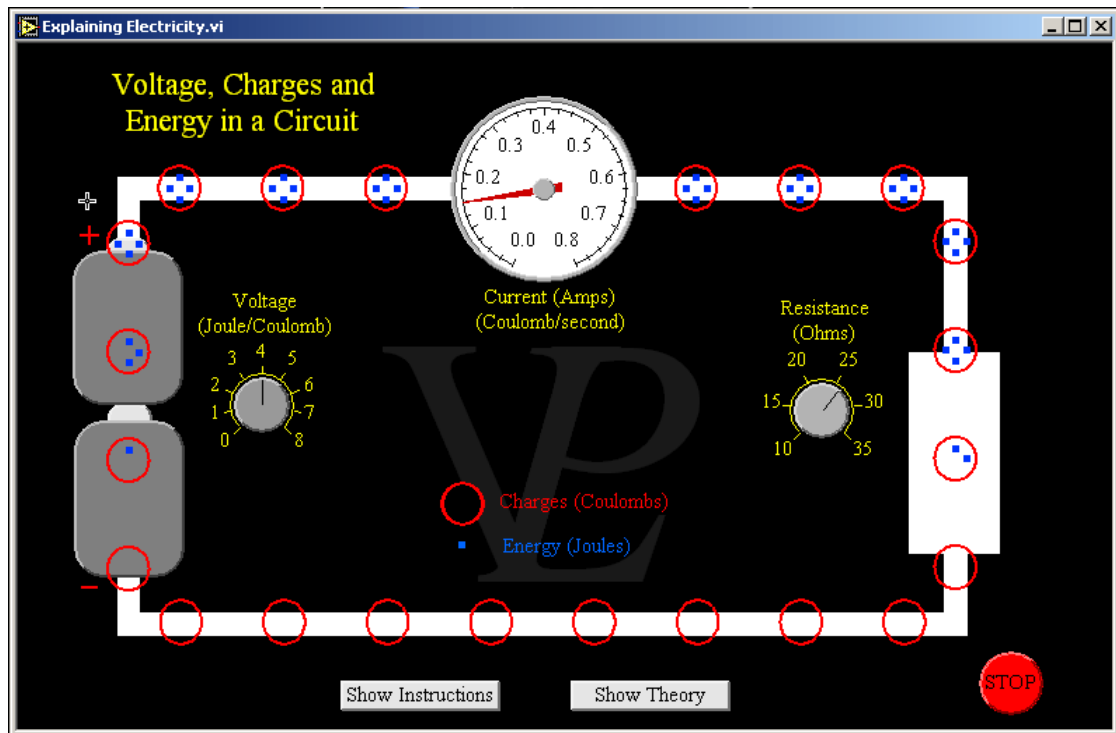
DC electricity is used in most of our portable appliances.
How do these circuits work?

Electricity DC 8.6

8.6 Explaining electricity

Basic

This visualisation program shows Coulombs of charge travelling round a circuit. They receive Joules of energy at the battery and dissipate them in the resistor. They finally return empty back to the battery to be re-filled.



This simulation is designed to show how the concepts of voltage, charge, current energy and resistance relate to each-other.

Charges exist in the wires of a circuit at all times, even if they are not connected to a battery! However, they are not moving. The unit of charge is the Coulomb (C). When a battery is connected to a circuit, it causes the charges to move from the positive terminal towards the negative one.

Potential difference (or Voltage) is measured in Volts. One volt will give each Coulomb of charge an energy of one Joule (a battery of 4 Volts will give each Coulomb of charge 4 Joules of energy). The charge will then travel around the circuit, but it will only spend that energy when it encounters resistance in the circuit. After the charge has spent its energy it will return to the battery in order to receive another 'allowance' of energy.

When the Voltage is increased, not only does each charge receive more Joules of energy to spend, but the charges also travel around the circuit faster (the current increases).