



# **Marine Electrics Notes**

by

**John Kennedy**

Science Master  
Smithfield State High School

© John Kennedy 1993

All rights reserved. No part may be reproduced without permission of the publisher.

**Published and printed by**

Wet Paper  
14 Milbong Tce  
Ashmore 4214



**Typesetting and computer illustrations**

Mark Moffatt

**Line illustrations**

Brady Moffatt

Cataloguing-in-publication data

Kennedy, John, 1953 -  
Marine electrics notes

Includes index  
ISBN 1 86283 037 1

1. Ships - Electrical equipment. 2. Electrical engineering - Problems exercises, etc. I. Title

623.8503



# Contents

An overview of electricity	...	...	...	...	...	...	...	...	...	5
Energy	...	...	...	...	...	...	...	...	...	6
Symbols used to describe electricity	...	...	...	...	...	...	...	...	...	8
Electric circuits	...	...	...	...	...	...	...	...	...	9
Amps	...	...	...	...	...	...	...	...	...	9
Fuses	...	...	...	...	...	...	...	...	...	9
Voltage	...	...	...	...	...	...	...	...	...	10
Exercise 1	...	...	...	...	...	...	...	...	...	13
Alternators	...	...	...	...	...	...	...	...	...	15
Marine radios	...	...	...	...	...	...	...	...	...	17
Depth sounders	...	...	...	...	...	...	...	...	...	18
Satellite navigation	...	...	...	...	...	...	...	...	...	19
Starter motors	...	...	...	...	...	...	...	...	...	20
Solenoids	...	...	...	...	...	...	...	...	...	22
A final word	...	...	...	...	...	...	...	...	...	23
Exercise 2	...	...	...	...	...	...	...	...	...	23
Answers to exercises	...	...	...	...	...	...	...	...	...	26
Index	...	...	...	...	...	...	...	...	...	28

## **Syllabus topics**

This set of notes fits into the following syllabus

Marine Studies topics

*Marine Communications*

*Boating Ashore*

Multistrand/Senior Science

*Energy*

*Matter and Materials*

Industrial Arts

*Electrical systems*

# What is electricity?

## The atom

At some stage your teacher will have talked to you about atoms. If you were not asleep, you may remember the following diagram.

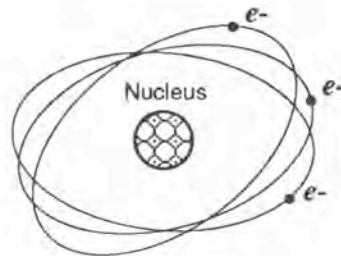


Fig 1 Atomic Structure

The centre of the atom is the nucleus and has a positive charge. The outside has a negative charge. A mutual force of attraction holds the whole lot together.

## Conductors and non-conductors

The negative charge is caused by **electrons** (note the similarity between this word and the word electricity). Some materials, like glass or wood, hold the electrons very tightly and so the electrons cannot move through the material. Other materials, in particular metals, hold the electrons very loosely and so, with only a relatively light push, we can get the electrons to move (flow) through the metal.

This, very simply, is the difference between conductors and non-conductors (insulators).

The next major idea you need to grasp is that electrons repel (hate) each other. Put two electrons near each other and they will try to move away from each other, (like when you're with your Mum in the shopping centre and she says something embarrassing to you in front of your friends).

You will probably understand that if you have a length of pipe full of marbles and you put another marble into one end, a marble will pop out the other end.

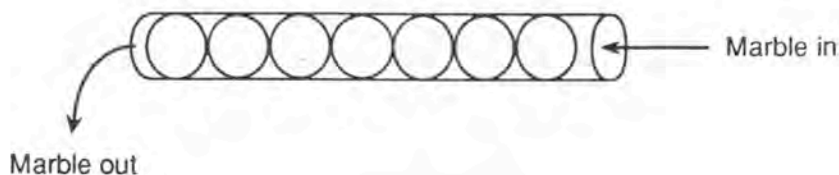


Fig 2 Marbles in the pipe

The marbles in effect, have "flowed" down the pipe.

Imagine then, a piece of wire full of electrons and you force a few electrons into one end. You will expect then that since the electrons don't like getting too close, some will "pop" out the other end.

It turns out that the best way to get electrons to flow is to push electrons in on one side, and drag them out on the other. While electrons are flowing, they can do work for us.

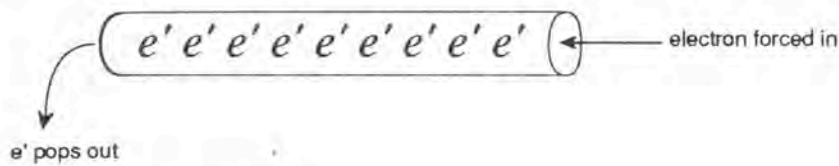


Fig 3 Repelling Electrons

There are many ways of getting electrons to flow. Some of the most common are batteries, generators and alternators. Household power is usually generated at a power station and is beyond the scope of this course.

Once electrons flow, this is called electrical current. The resistance to this flow is, naturally enough, called resistance.

## Energy

There are many types of energy - Kinetic (the energy of motion), Potential (Stored Energy), Solar, Chemical (Petrol) and so on. The overall source of all energy is the sun.

Energy is the ability to do work and can be defined with fancy formulae such as  $E = 1/2 mv^2$  and  $mgh$  (your teacher can give you examples). Energy can also be described in simple terms such as, that big motor has the ability to move the prop very quickly.

An important feature of energy is that it can be transferred from one form into another. Rubbing your hands causes your hand to get warm. Kinetic energy is transferred to heat energy. In many cases when engines do work, heat is produced. This means the machines have to be cooled requiring more parts and so reducing efficiency. In the past light bulbs were up to 80% inefficient but now with more intricate design can be made to last up to 10 times longer.

The idea of energy convertors is to take an energy source and convert it into an useful application. Petrol is converted in a engine to make the prop turn to drive a boat. The engine can be used to make electricity in a generator.

### A simple energy convertor

Consider a coil of wire, a circuit with an very sensitive electricity meter (called an ammeter) and a magnet. If the magnet is pushed into the coil, the milliammeter will register a current. The magnet has caused the electrons in the wire to move as illustrated in Figure 3.

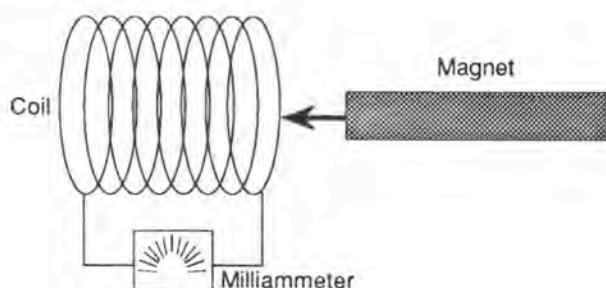


Fig 4 A magnet and coil can be used as a simple energy convertor

The next question is how we get magnets or coils to turn? The answer came long ago with the first steam driven turbine. We can however use water to turn turbines in the basic water wheel experiment as shown in the figure below.

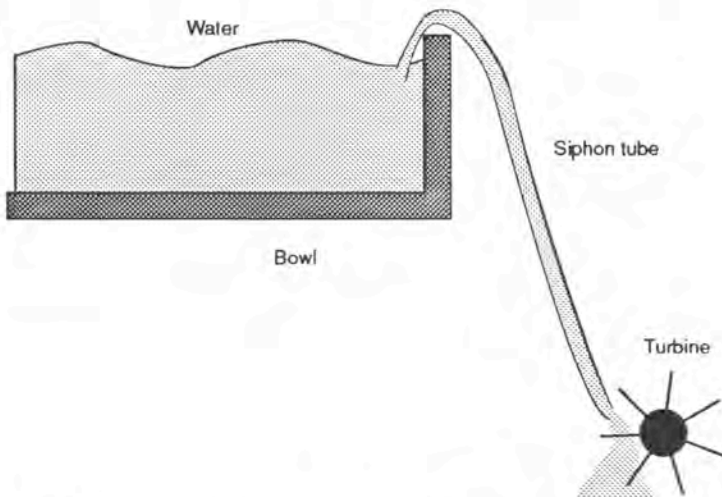


Fig 5 Water can be stored in a bowl and used to drive a model turbine

## A large energy convertor

A hydroelectric scheme as shown below can also be used to generate electricity on a larger scale.

Here stored water falls through pipes which drives turbines some distance below.

The turbines in turn drive powerful generators which make the electricity. The water is then returned to its normal entry to the sea by the river. One environmental issue to consider is the dam that was used to store the water. The water in the dam covers many valuable areas used as homes for animal and plant species. Careful planning and management is necessary for schemes such as this.

This electricity is carried to cities and towns some distance away by power lines.

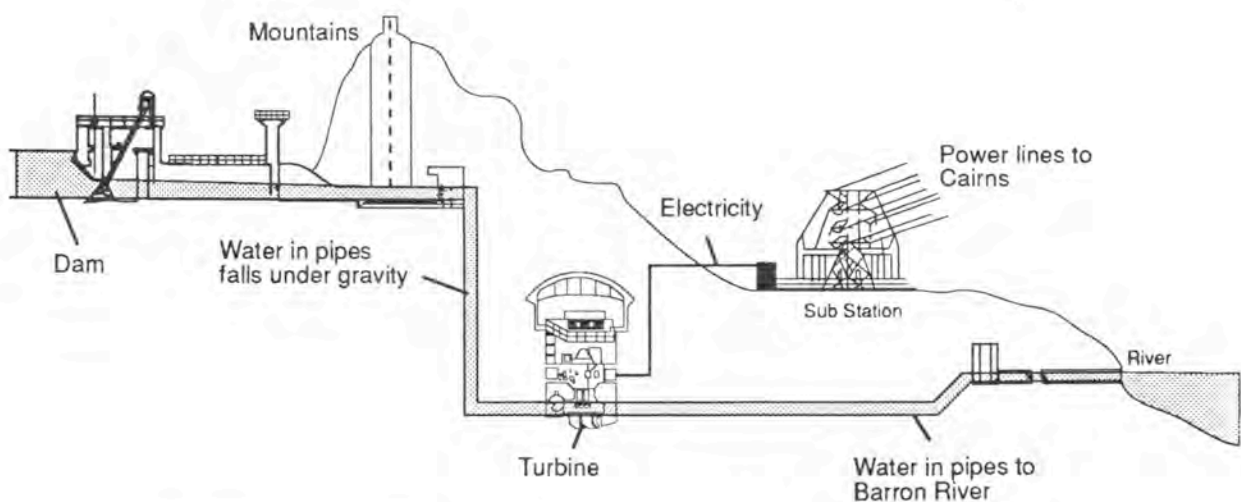


Fig 6 A hydroelectric power scheme (Adapted from QEC Brochure on the Barron River Hydroelectric Power Station)



Once this electricity reaches homes it can be used to drive electric motors. This is another energy converter and can be demonstrated by the simple match box motor as shown in Figure 7 below.

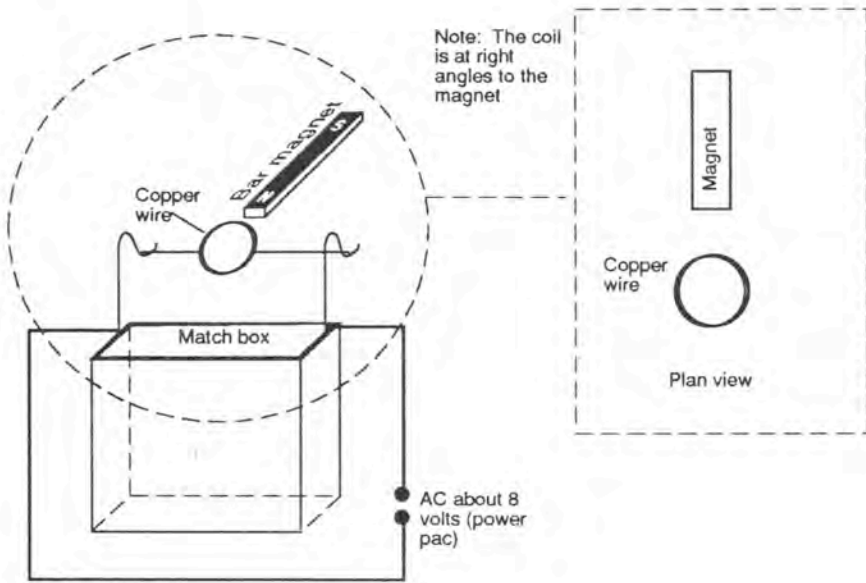


Fig 7 A simple match box electric motor

## Symbols used to describe electrical components

Rather than just drawing the components (or parts) of electrical equipment, symbols are used. Some common symbols used are:

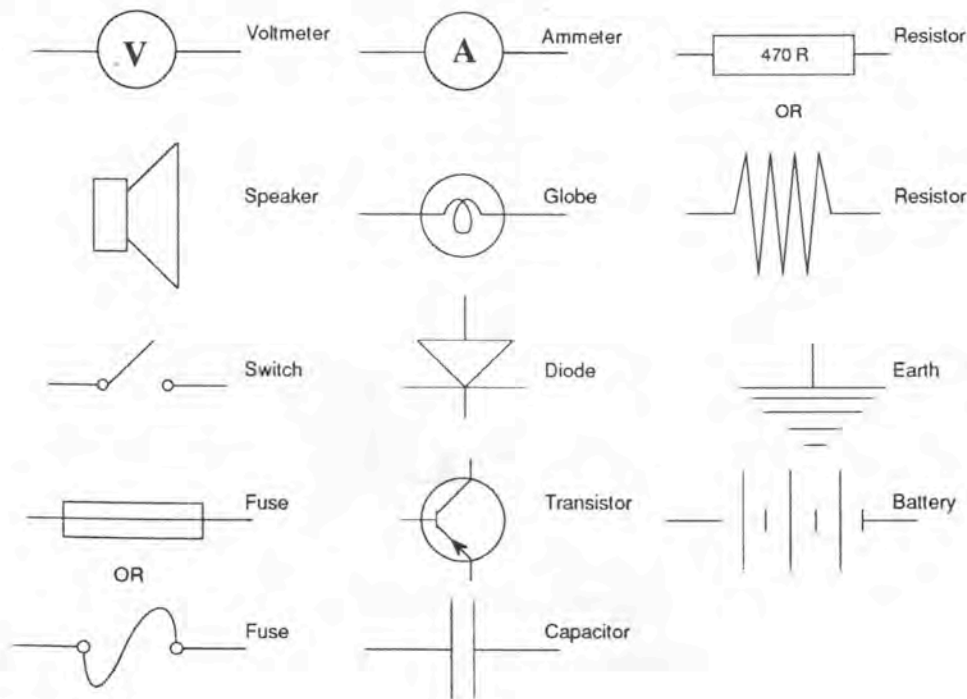


Fig 8 Common electrical symbols

# Electrical circuits

As mentioned, electricity needs to be pushed and pulled around the wires. Electricity then flows in the circuit. As soon as the circuit is broken the flow stops.

## A simple circuit

It consists of a battery, a globe and a switch, (in this case, open). Once the switch is closed, electrons will flow around. The electrons flowing through the globe will do work. In this case, make some light.

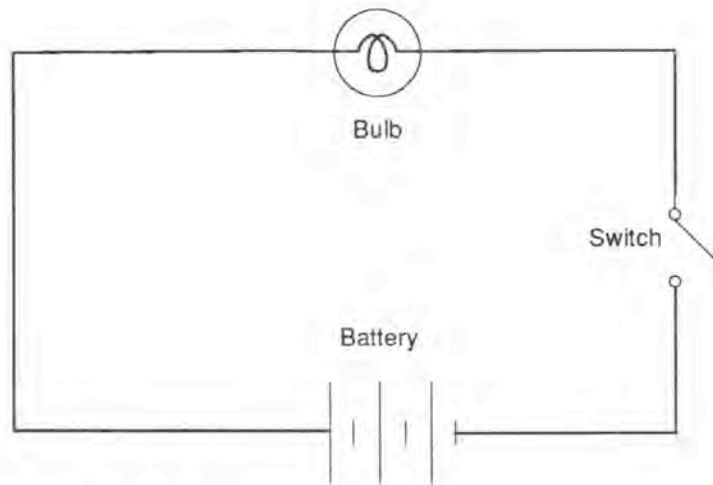


Fig 9 A very simple circuit

The more flow, the more light.

## Amps

Flow is, in fact, measured in **amperes** or Amps for short. The symbol used to signify amps is simply A. For example, 5A means 5 amps.

Current is measured by an instrument called an **ammeter**.

It is not unusual to see an ammeter on instrument panels. Many of the electrical fittings and wiring in boats have a limit to how many amps they can handle before failing (usually melting). The problem is, as the electrons flow, they create heat which tends to melt thin wires and upset some of the delicate insulators and even some of the electrical components themselves.

It is easy for example to, "blow" a 5 amp bulb by allowing, say, 6 amps to flow through it. Every now and again, such disasters occur, especially in boats where vibration, wave pounding and even trailering on harsh roads can all help to break wires and shake components loose. This is why we have fuses.

## Fuses

Fuses are usually just a piece of wire which melts when a certain current is reached. For example, a 5 amp fuse will melt or "blow" once 5 amps of current is exceeded.

Fuses come in many shapes and sizes, but the best ones for marine application are glass tubes with stainless steel caps on each end.



**Note:**

Just because you can have two 12V batteries on a boat, it doesn't mean the boat runs 24 volts!

Many a person has discovered to their surprise that joining two batteries one way can make the voltages add or joining them in a different way makes no difference to the overall voltage.

Join them the wrong way and you'll probably blow every fuse in the boat. The difference is whether the batteries are connected in **SERIES** or in **PARALLEL** circuits.

**Example:**

On the left hand side, negative is connected to positive on the next battery. On the right hand side, positive is connected to positive on the next battery.

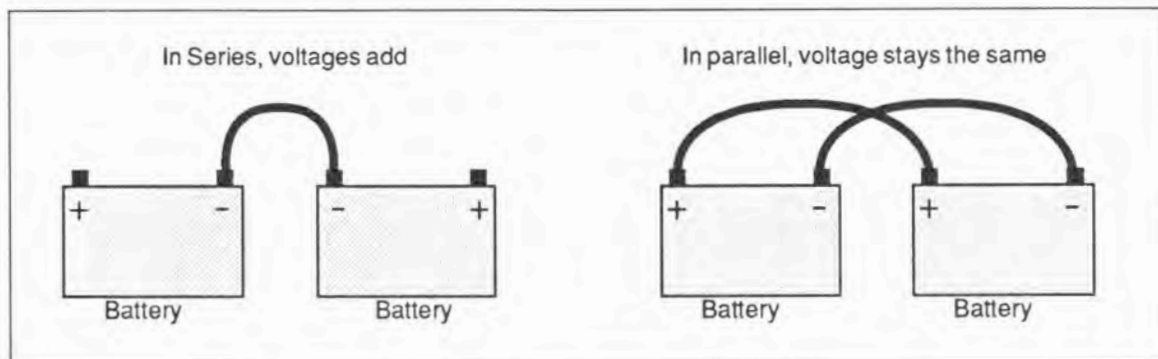


Fig 11 The difference between series and parallel

In real life, you'll find that it is sometimes difficult to see which way your boat is connected, so be careful.

- Label any wires you disconnect.
- It helps too, if you remember that RED wires always got to positive and BLACK wires to negative.

Always, that is, until the boat builder runs out of black cable and uses red for everything, or someone decides to add wiring into the vessel and is either colour-blind, ignorant or just couldn't be bothered getting it right.

I can't see how it happens, its so easy to get it right, but believe me, I've pulled the hatches off a few 3/4 million dollar game boats and found a mess of wires, (all the wrong colours) that would do a spaghetti factory proud. Check back at the battery terminals (they are the lumps of lead sticking out the top), one will be marked '+' and the other '-' (usually). Take it that the battery knows what it's doing and work from there.

The advantage of joining two batteries together is that they can produce a flow of amps longer than either could on its own.

That is, if a single battery can deliver 15 amps for 15 minutes, then two of them in a parallel could do it for 30 minutes.

This is valuable, especially when trying to start an engine; more so if it's having trouble starting. Generally, diesel engines need more "cranking power" than petrol engines.

Let's have a look at some circuits and see what they mean.

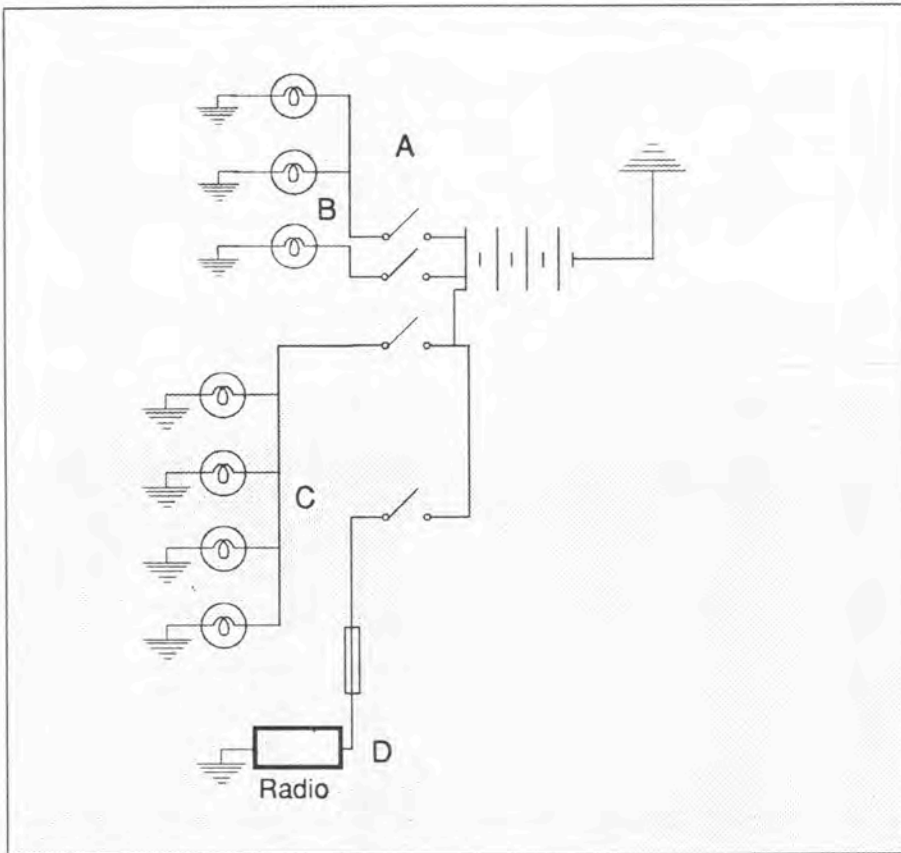


Fig 12 Battery feeding to circuits

In Figure 12 we see one battery feeding power to many circuits. Notice that the bulbs at A both work off the one switch. That means when the switch closes, both bulbs light up. It is not possible to turn one bulb on without the other.

This sort of system is used for navigation lights where both port and starboard lights come on together.

Notice too, that the bulbs are drawn as being together, whereas in real life, they go on to two sides of the boat. This makes life a bit confusing because the diagram gives the impression they are together.

B is a single bulb on a single switch. It can be turned on or off on its own at any time. This sort of system is used for map lamps, reading, toilet lights, etc. C has four bulbs in parallel: close the switch and all four bulbs light up. Sometimes these can be tricky because instead of a switch, the lights are connected to the key or ignition system.

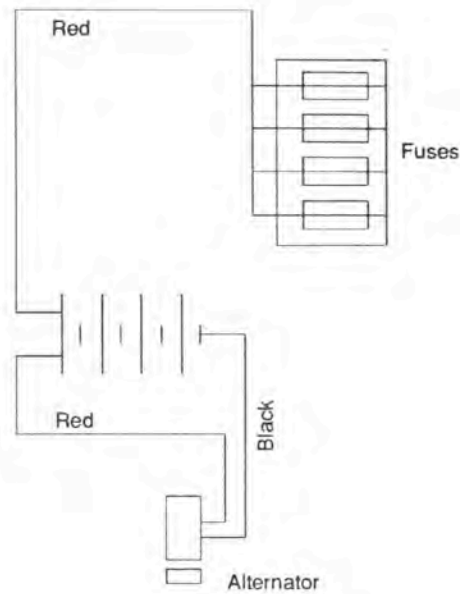
Usually you can work back from the fittings, find a colour other than black or red and then trace it back. If it leads back to the ignition switch then that is obviously what turns it on/off. Notice all the "earth" symbols (**symbol**). It's a way of eliminating wires in a metal boat. Most boats however, have wires going to and from fittings. Use of "earths" on boats cause corrosion.

For this reason, a wiring diagram actually shows colours where wires go and the approximate relationship of different items on the boat.

Examine the following idea:

This is better. At least we know that the alternator is supposed to have a black wire feeding power into one side of the battery, and a red to the other.

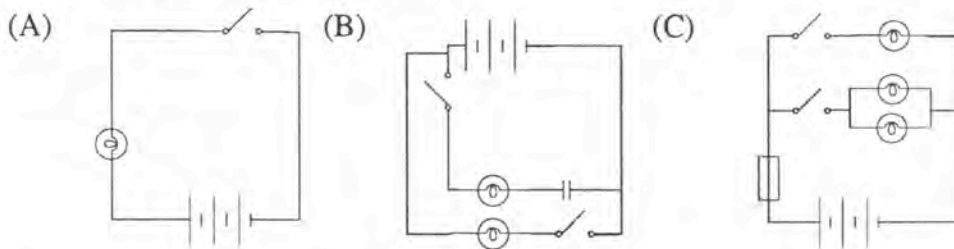
Figure 13 Colours in a circuit



## Exercise 1

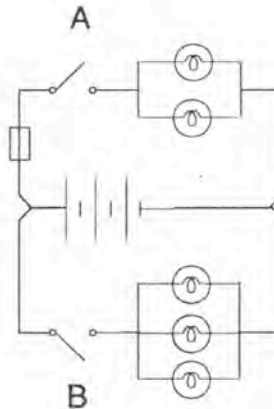
(Do not write on this booklet.  
Answer on your own paper)

1. Label all the parts in this circuit.

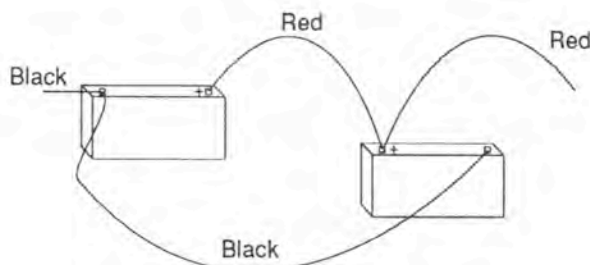


2. Look closely at this circuit.

- When switch A is closed and B is open, how many lights will shine?
- When switch A is open and switch B is closed, how many lights will shine?
- If the fuse "blows", which lights will not work no matter which switch is closed?
- If the fuse blows, are there any lights that will still light up?

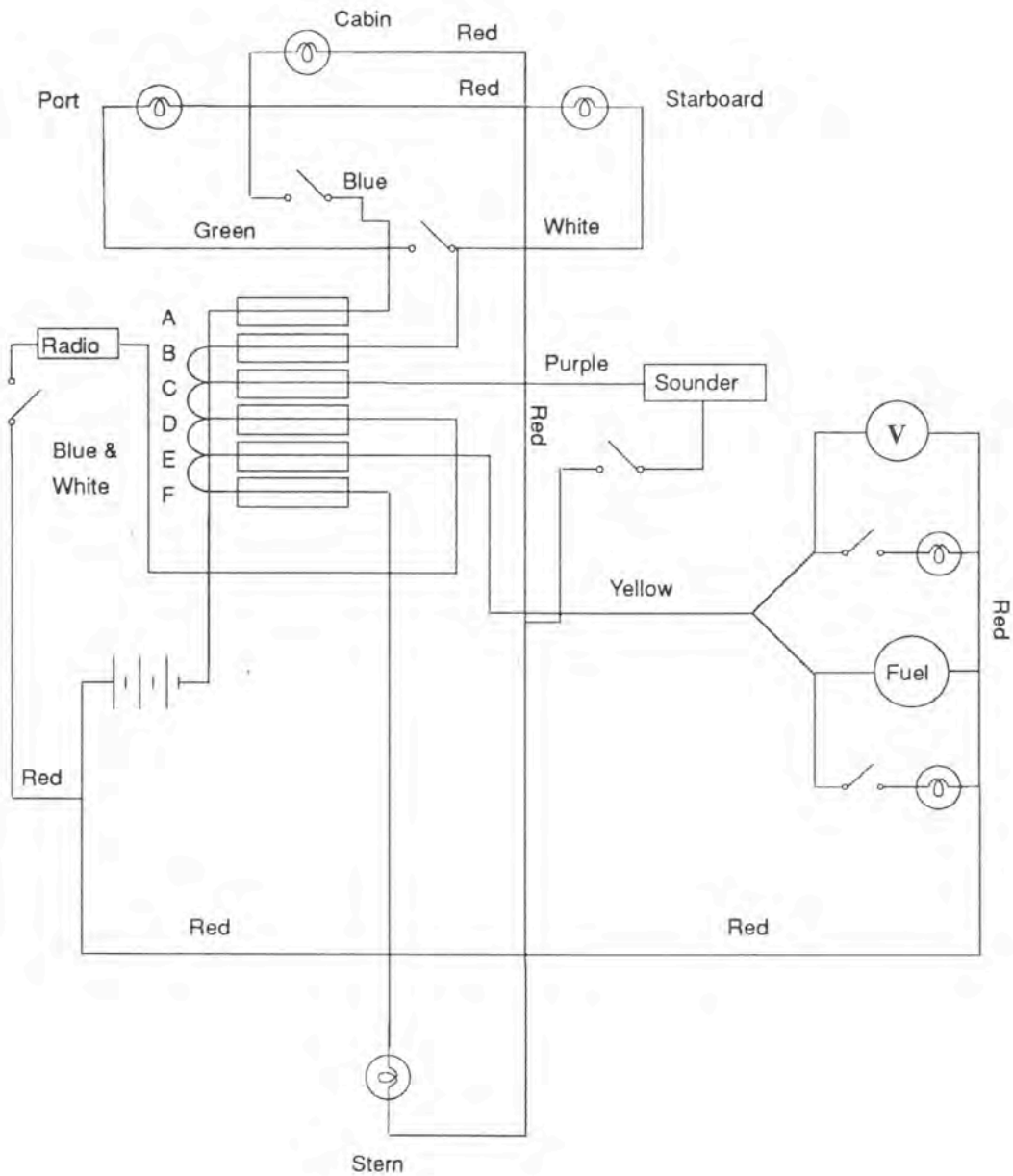


3. Look at these batteries.



- Are they in a series or a parallel?
- Is the colour coding of the wires correct?

Q 4.



- (a) Which coloured wire takes power to the cabin light?
- (b) Fuse E has blown. Which electrical component(s) won't work now?
- (c) Which fuse protects the radio?
- (d) I find a white wire hanging loose. Which component does this wire belong to?
- (e)
  - i) Which two instruments run off the yellow wire?
  - ii) Consider the lights which illuminate these instruments. Are they switched to come on together or independently?
  - iii) Are the instruments on a switch? When would they come on?
- (f) The radio will not come on. I've checked the fuse and it is O.K. Where would you look for problems?

# Alternators

Logic tells you the alternator is producing electricity while the motor is running, and these wires are feeding this power to the battery.

So, if the warning light comes on telling you the battery is not charging, a few things could be wrong:

- a. One of the wires has corroded off,
- b. the fan belt is broken or
- c. the alternator is stuffed. How do you check?

The best way is to let the motor run and put a voltmeter on to the wires as they leave the alternator.

An alternator that is running (above engine idle speed) should be putting out about 13.5 to 14.5 volts.

Often the wires will join others where they merge from the casing; put the voltmeter leads on to them there.

If the needle doesn't move, swap the voltmeter leads around, you may have them on back to front.

If you don't have a voltmeter, a light bulb (12V of course) will do. Pull out one of the navigation lights or an internal light bulb and put that across the two wires. A brightly glowing bulb gives you some idea that all is going well (but make sure you are not getting feed back power from the battery). Figure 12 explains this.

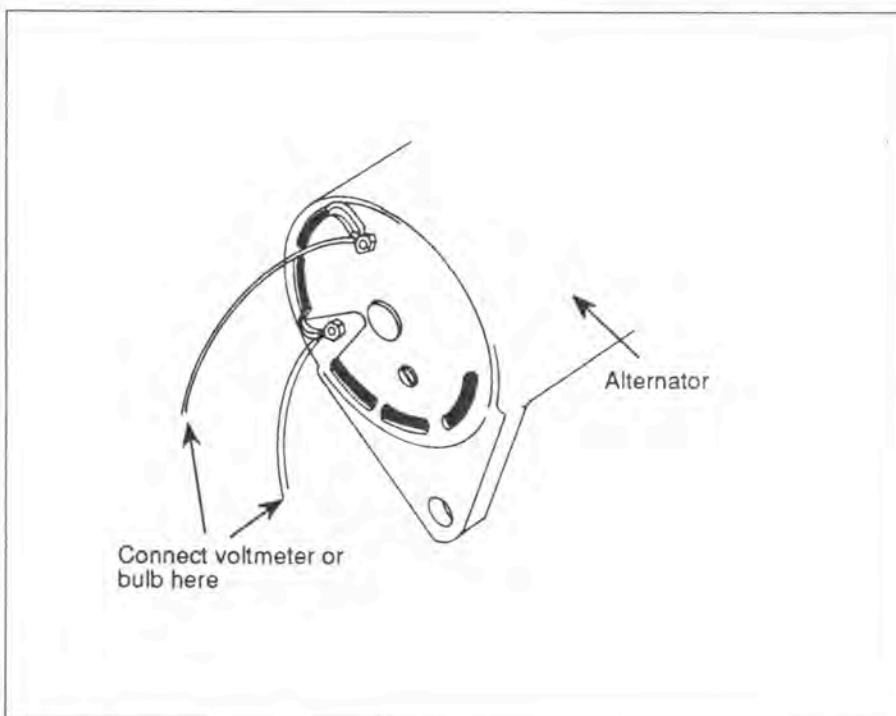


Fig 14 Alternator

Look at the cutaway diagram of the alternator (on the next page) for more details.



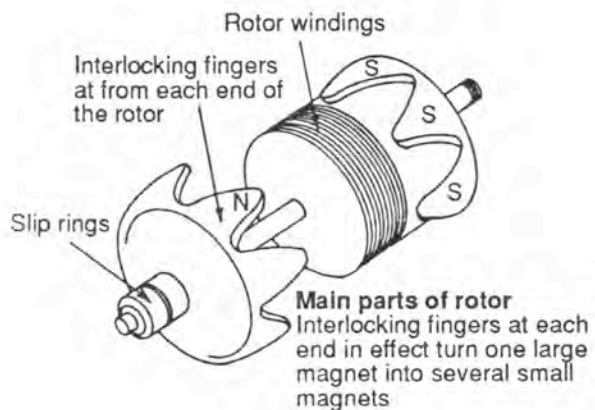
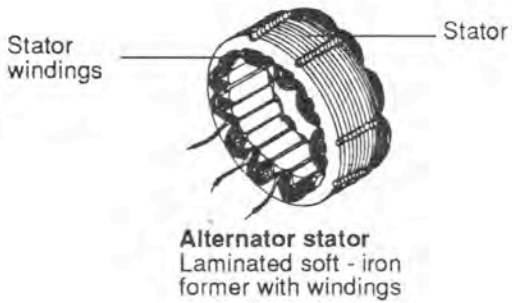
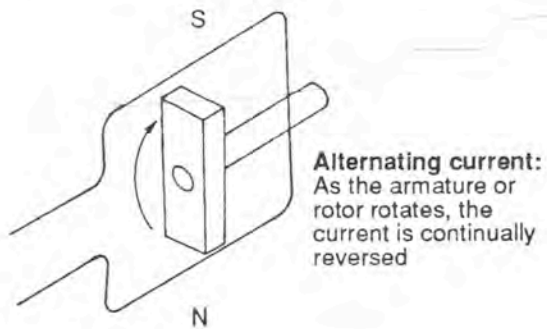
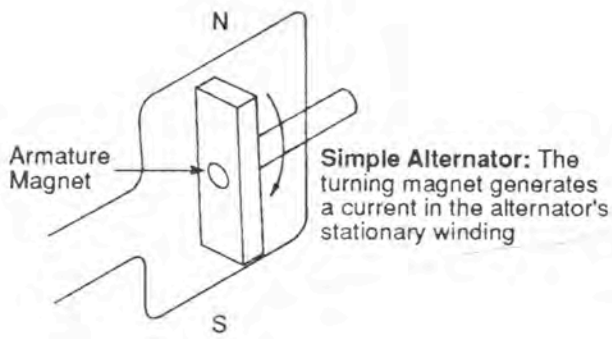


Fig 15 Parts of an alternator

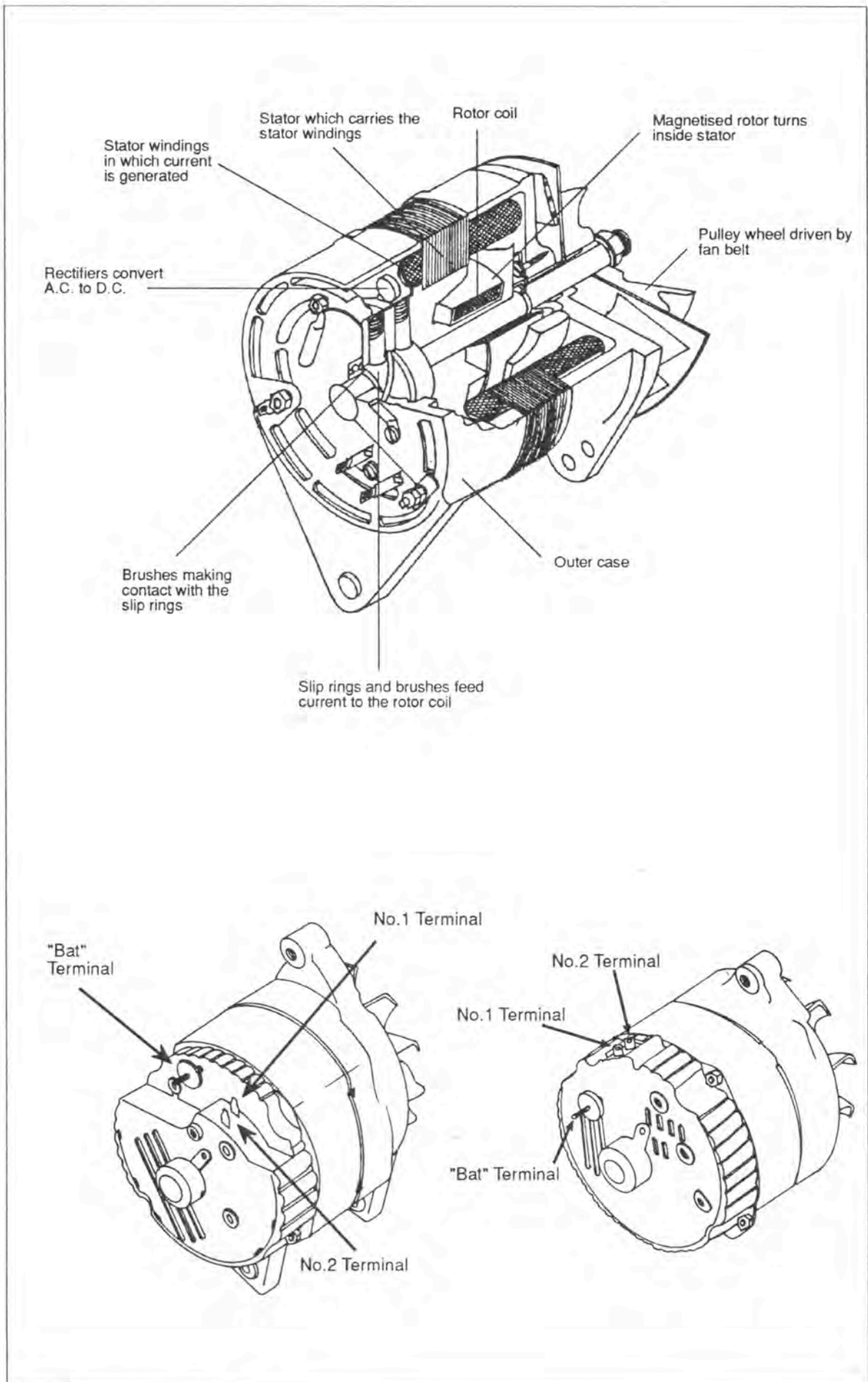


Fig 16 Cross section of an alternator

If no power is being produced by the alternator, forget it. Wait until you get home, unbolt it and take it to a car electrician specialist. Label the wires or make a diagram and be prepared for a substantial bill.

Outboards, by the way, have a different system- don't even think about playing with them unless you see a loose wire flapping around and can see where it belongs.

If you wrongly connect wires in an outboard you can blow up the dreaded "black box".

Symptoms of this are an outboard dealer with a grin from ear to ear, trying to be sympathetic and telling you how rarely this happens. At this point a big loan from the bank will be appropriate.

While you are connecting the voltmeter you will probably get some blue sparks jumping around. This is not really dangerous unless you happen to have a petrol leak (in which case the electrical problem will pale to insignificance at this stage).

What is dangerous is the fright you get. As you leap back and get your shirt caught in the fan belt, you may find yourself being dragged into the bowels of the engine bay. This is not a desired outcome at all.

Be firm with the probes and make sure that you are well back from the moving parts on the engine(s). Better yet, have someone near the key ready to turn off the engine at the first ear-piercing scream.

## Marine radios

### Radios and related problems

Any two-way radio set can be broken down into the following parts:

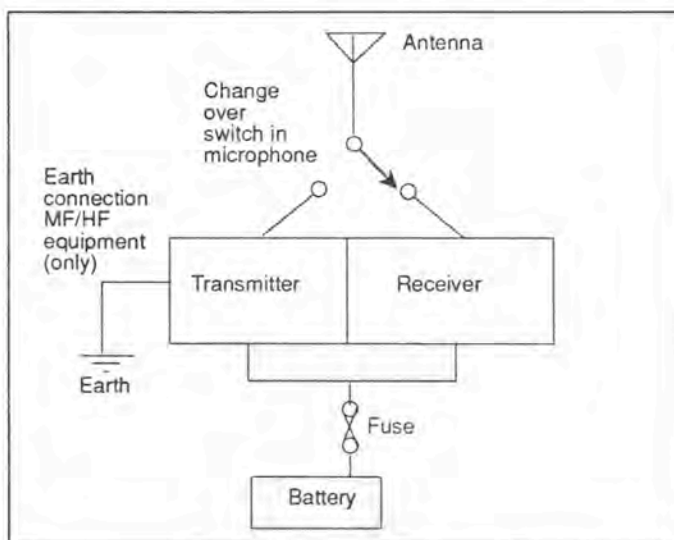


Fig 17 Two-way radio setup (After Dawson 1992)

### Operation

On the CB radio is a small needle which moves when you press the button to speak. On one end of the scale is a "TX". This is fancy talk for "T"ransmit (don't know how they get X out of that). If the needle doesn't go right up near the top of the scale, something is wrong and means no signal is going up to the other people.

Several things could be wrong. Let's eliminate a few:

- a. Check the radio is still switched on.
- b. Listen to the radio for any outside signal. That is, can you hear anyone speaking on any of the channels?

Do you get background static when you turn up the volume and down on the squelch? If you can't hear anything, but the dash lights are on, perhaps the speaker has been disconnected/ broken. At this stage, you may have to give up. If, however, when you press the button and speak, the TX needle flickers, you may be getting a signal out but not hearing the replies. Tell them you're not receiving and make the call simple. Check for thick salt crust on the aerial - this can block out in-coming calls completely.

- c. When you press the button, all the lights on the dash go out or fade away. This means your battery is flat. Your signal will be very weak. Check the battery terminals for corrosion. A piece of sand paper will be useful here.
- d. No lights, no noise, switch on. Check for a blown fuse. If you replace the fuse and it blows straight away, look around for other faults, like loose wires. Smoke pouring off wires is not normal!!

Switch everything off and investigate the source of the smoke. Wires that burn your fingers have been carrying too many amps. Separate them and try to find any loose wires.

Any faults you can fix will all be on the outside of the radio, don't even look for a screwdriver to open it up unless you can afford to buy a new radio.

An earth is only needed for more powerful sets (HF and SSB).

On these types, the earth works with the aerial and not having one reduces its effectiveness. (Ask a dealer if in doubt).

## Batteries

Lead/Acid Batteries ( the same as in a car) are best checked with a hydrometer.

The hydrometer will show you how charged each cell is.

You suck up the fluid in the battery and read the scale on the floating part in the middle. A fully charged battery should read between 1.250 and 1.280

Some points on batteries:

- Use only distilled water, normal water contains salts which kills batteries.
- Heavy charging will bend the plates inside the battery and shorten its lifespan
- Batteries last much longer if they are used. Short periods of use followed by gentle charging.
- Saltwater can wreck a battery faster than dropping it off a tall building. One of the major problems with submarines during the war was encountered if seawater and batteries mixed. The resulting gas can kill you if you breathe it in.
- Don't smoke near charging batteries. It won't give you cancer but it could blow your head off. Charging batteries gives off hydrogen gas

# Depth sounders

Depth sounders fall into the "black box" category as far as I'm concerned.

If you have checked the fuse, (usually in a small white plastic container in the wire that comes into the sounder), checked it's on and looked for loose wires, then that's about it. Take these to the friendly dealer.

A few hints though: seawater and depth sounders don't mix, so keep them dry. Around humid areas such as Cairns, the heat can badly affect both the plastic case and some of the internals.

**Do not** install a small fan to blow air through any components like sounders or radios. This may work on land but all it does is blow salty air on hot metal components - a great way to accelerate rust and corrosion. Keep them in shaded areas or build a small shade cloth cover for them.

# Satellite navigation and radar

These fall into the same category. Eliminate the obvious faults but don't investigate inside. Radar units put out heaps of energy so they can flatten a battery system very quickly. They can give you quite a lift if you touch the wrong parts too. Again, this sort of thing should be avoided.

# Starter motors

## Mechanical problems

A starter motor is just a big electric motor which will crank over the main engine until it starts. Have a look at any starter motor and you will notice it has really thick wires feeding it. (See also the circuit diagram showing starter and alternator.)

That's because, electrically, they are hungry and it takes a thick wire to carry the amps needed to make them go.

Even these thick wires get quite warm if the starter is operated continuously - so don't operate them continuously.

A 5 to 20 second burst is all they can handle. Operated for long periods they behave like old teachers, they suffer burn-out. Once that happens, they won't work at all (the starter that is), and will need to be re-wired (another mega-bill).

As the starter is operated, power drains from the battery and if it is a petrol engine, this can be enough to stop a spark being generated. Once the engine gets to the stage that it rolls over in a series of herniated groans ..whurr..whurr..whurr...click, click.... you can put the pencil through the idea of it starting the engine.

It's time to start kicking yourself for not calling for help before the battery died. If you wait for say, 15 minutes, sometimes the battery will recharge to some extent - but don't count on it !!

If you turn the key and you get a series of clicks, the problem is either a flat battery or not enough power actually getting to the solenoid / starter.

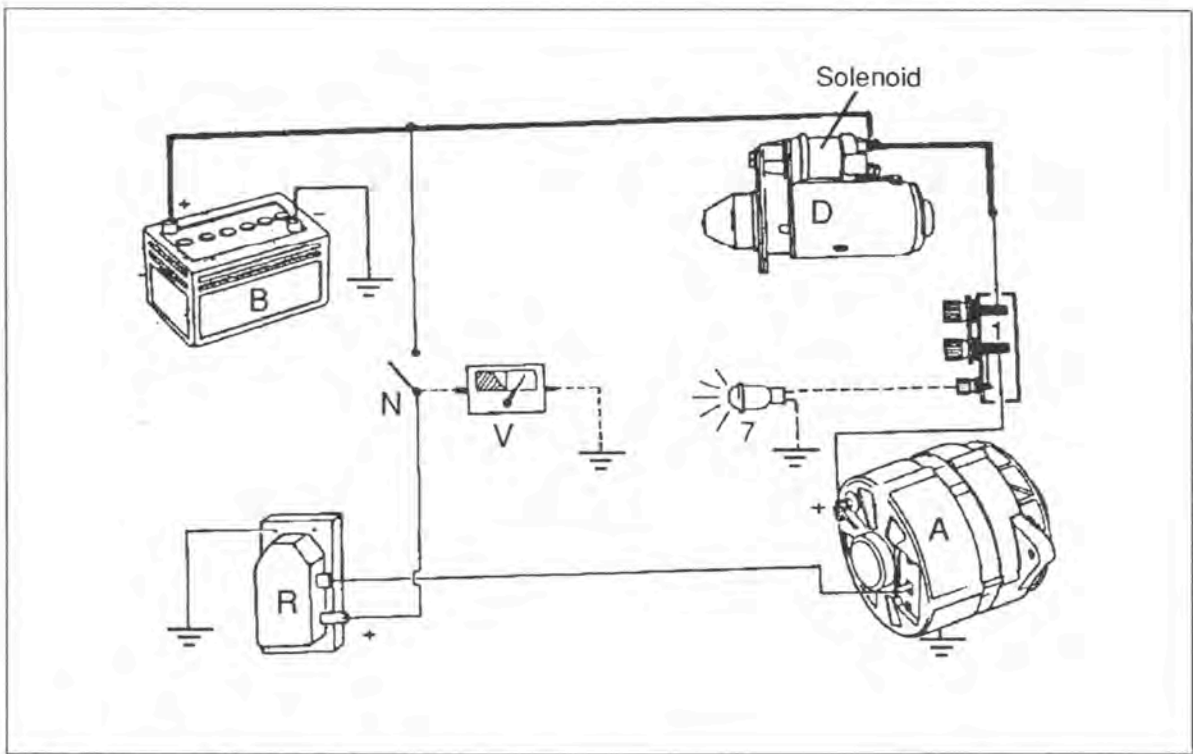


Fig 17 Example of a circuit with alternator and starter

## Solenoids

What' a solenoid?

Because the starter needs so much electricity, it needs a big switch to turn it on and off. You guessed it; that's the solenoids job. Check the connections to it. Solenoids also have a thrust arm. This means that at the same time the starter starts doing its turning, a small arm shoves a gear into place which joins the starter to the engine. Marine engines are notorious for getting this small gear jammed in the wrong place. (See "Bendix starter drive.") A bash on the side of the solenoid with a hammer may cure this but can lead to very expensive damage and is not advised.

Spray down inside the starter with WD-40 or similar product. Actually, CRC make a lubricant spray that doesn't catch fire so I prefer to use that. Now just because the starter goes after a spray doesn't mean it's completely cured!! When you get home, get it checked! Next time (and that won't be far away) a spray and a bash might not work.

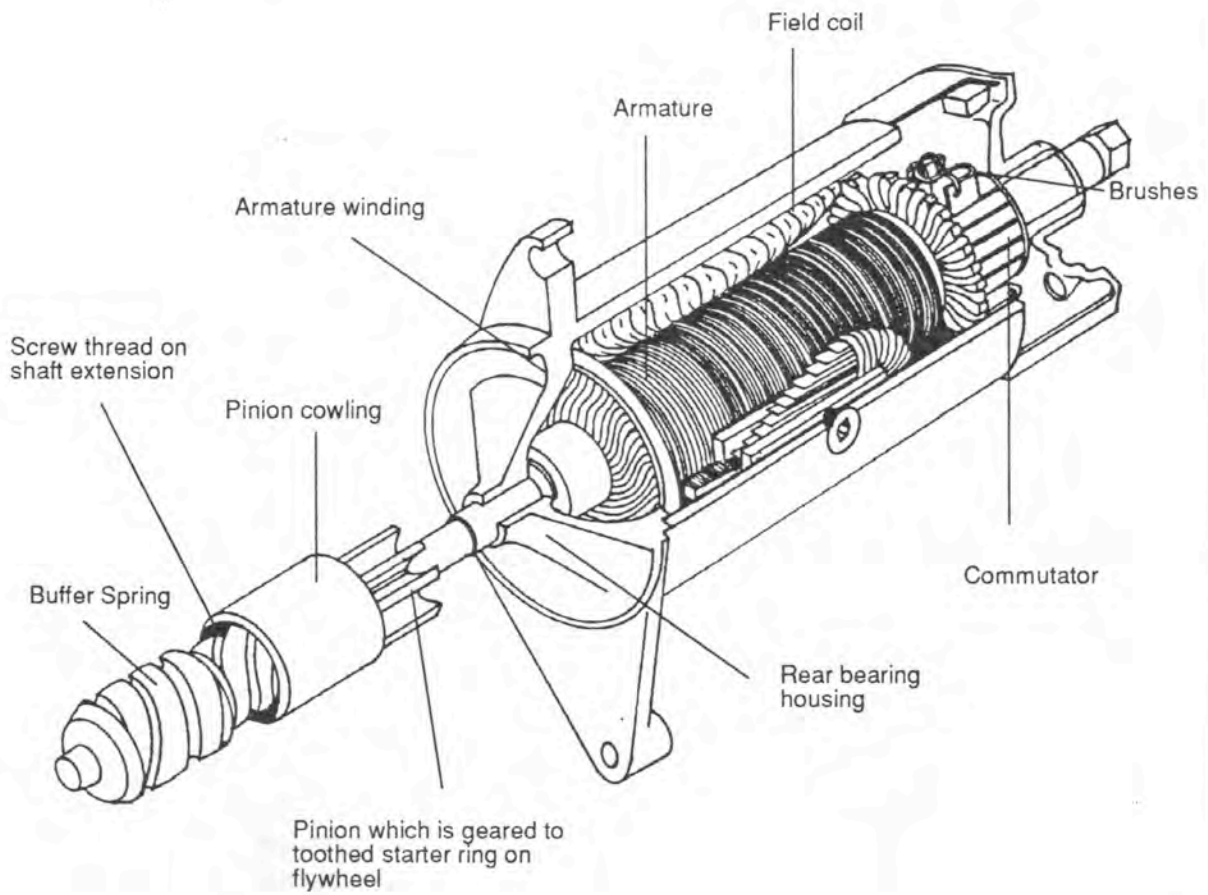
## A Final Word

Whenever you work on electrical components, it is most important to make sure you have good connections.

Once corrosion, rust and just plain old oily crud starts to work on wires and electrical components, you can just wait for troubles to start.

Keep things as clean as possible, a light spray with a suitable protective oil will extend the trouble-free period.

**Starter Motor:** A toothed pinion moves along the rotating shaft of the motor which is operated by current from the battery to engage with teeth on the flywheel and turn it to start engine



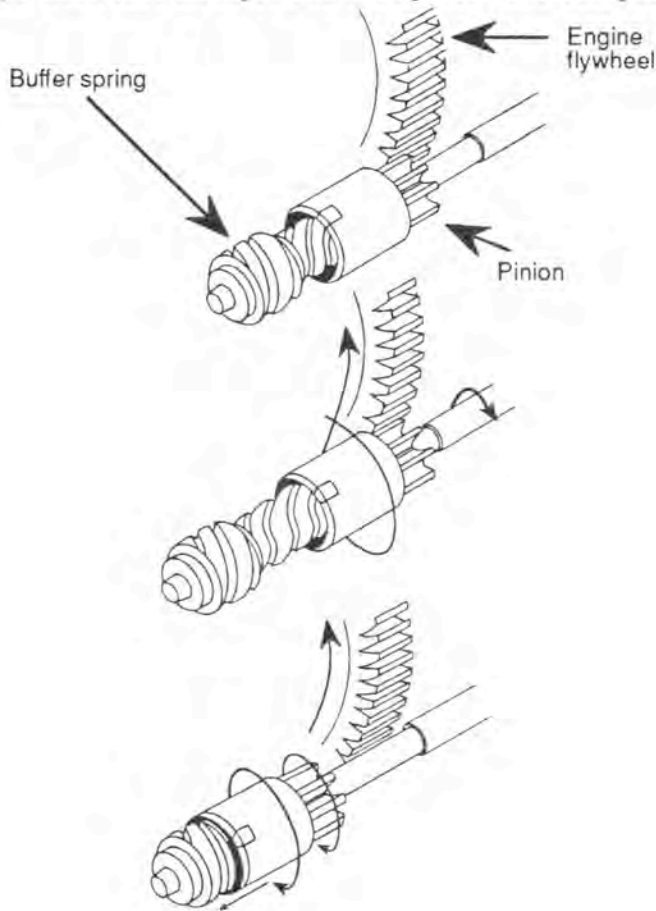
Spread of the starter motor

The view that a boat will never have electrical problems is an extremely naive one. Take a few spares, like bulbs, fuses and some basic tools to help fix things.

Sometimes you cannot repair things but you'd feel pretty silly if you knew what was wrong, knew how to fix it but didn't have any tools!

Keep an eye out for white or blue crystals along terminals, it's called terminal corrosion and sometimes that's exactly what it produces. Clean it off and put grease or oil over the terminals.

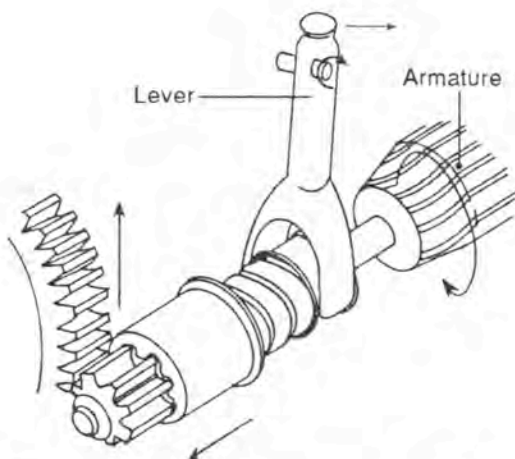
If it persists, take an aspro and seek professional help.....



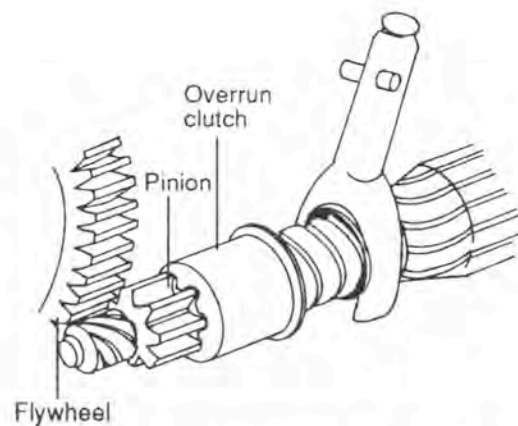
**Bendix Drive** Shaft begins to turn: pinion turns more slowly and is screwed forward to engage with the flywheel

Pinion at end of screw-thread engages with flywheel so that starter-motor shaft, pinion and flywheel rotate together

When engine fires, flywheel drives pinion faster than shaft, screwing it back along thread and out of engagement



**Pre-engaged starter** An overrun clutch allows pinion to turn with flywheel.



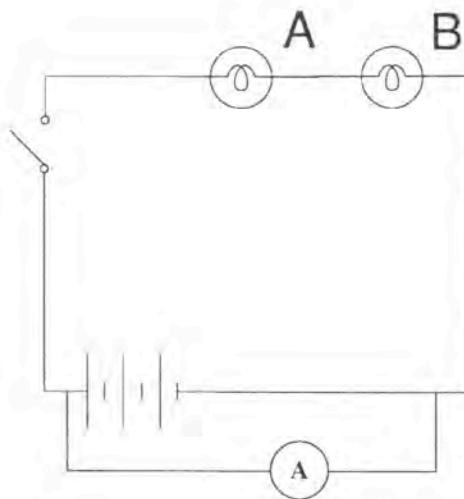
Lever releases pinion from flywheel when the starter switch is released.



## Exercise 2

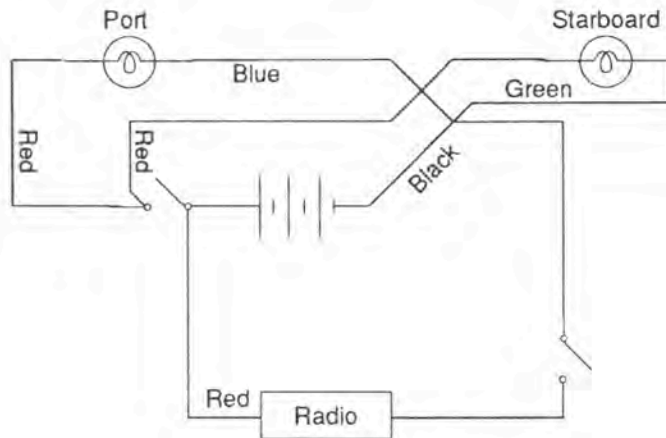
Do not write on this booklet Answer on your own paper.

1. What do you think is wrong in the following cases? State what you would do.
  - (a) I turn the ignition key but get absolutely no response at all.
  - (b) The radio is receiving calls from other vessels, but when I transmit the dash lights go out. No one calls back.
  - (c) A red wire is hanging loose; to which side of the battery should it be connected?
  - (d) The alternator "charge" light comes on. List at least three things that can cause this.
2. Turning on the toilet light blows a fuse and you can smell smoke. What is the problem?
3. A radar unit is rated at drawing off a working current of 8 amps, with a maximum of 12 amps. What size fuse should I use to protect it?
4. Examine this circuit:

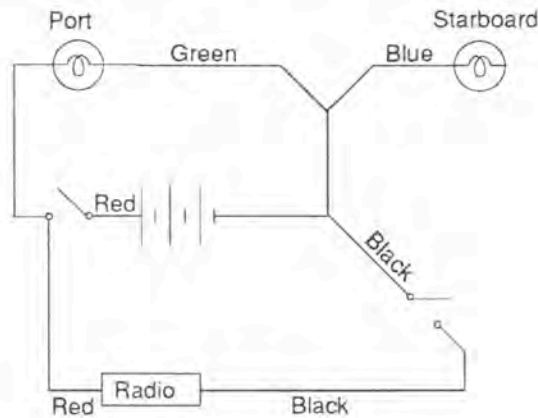


- a. Can I switch on bulb A without bulb B turning on as well?
- b. When does the ammeter come on?
- c. Re-draw this circuit so that the bulbs can be switched on independently and the -A- comes on with bulb A only.

5. Here is the wiring section of a vessel. It shows power to a radio and the navigation lights. (To make it easier, the fuse box is omitted.)



Unfortunately, this is what the real circuit looks like:



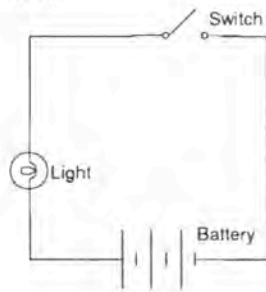
What problems will this set-up have? Will the navigation lights work? Will the radio work?

6. Draw a simple circuit for a small boat which will have the following:
  - a) navigation lights which come on together;
  - b) a stern light which is switched by itself;
  - c) a chart lamp;
  - d) a lamp for the speedo.
7. Which would draw the most power, a starter motor or a pair of navigation lights?
8. It's pitch dark, you are in a busy shipping channel. Your vessel has a cabin light, navigation lights, stern light and a toilet light. The port light bulb blows. What do you do?
9. A fuse on the depth sounder blows. It's a fuse but you only have a 3A and 10A fuse spare. Which one do you use?
- 10 When you turn on the ignition, key all you get is a series of clicks but it doesn't turn over. What could be wrong?

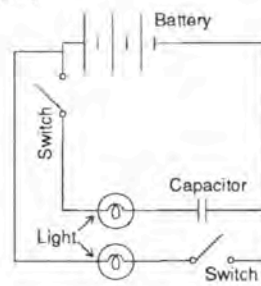


### Answers to exercise 1

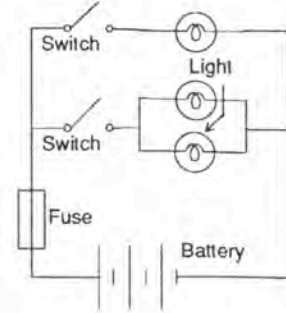
1. (A)



(B)



(C)



2. (a) 2 (b) 3 (c) Side A (d) Yes, Side B.

3. (a) Parallel (b) Yes

4 (a) Blue

(b) Voltmeter, fuel gauge and the lights that illuminate them.

(c) D

(d) Starboard light.

(e) i) Volts and Fuel.

ii) Independently.

iii) All the time.

(f) Blue and white wire connected? Red earth wire connected? Switch closed?

### Answers to exercise 2

1. (a) Blown fuse; dead flat battery; battery isolation switch "off".

(b) Flat battery; severe short in radio.

(c) Positive.

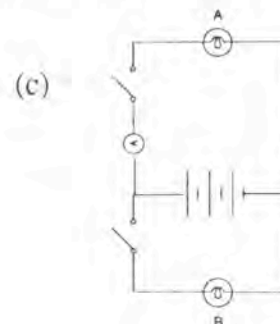
(d) Broken fan belt; alternator not charging; loose wire at alternator; regulator/diodes blown.

2. Short circuit somewhere between switch and light, smoke from very hot wires.

3. 10 amp.

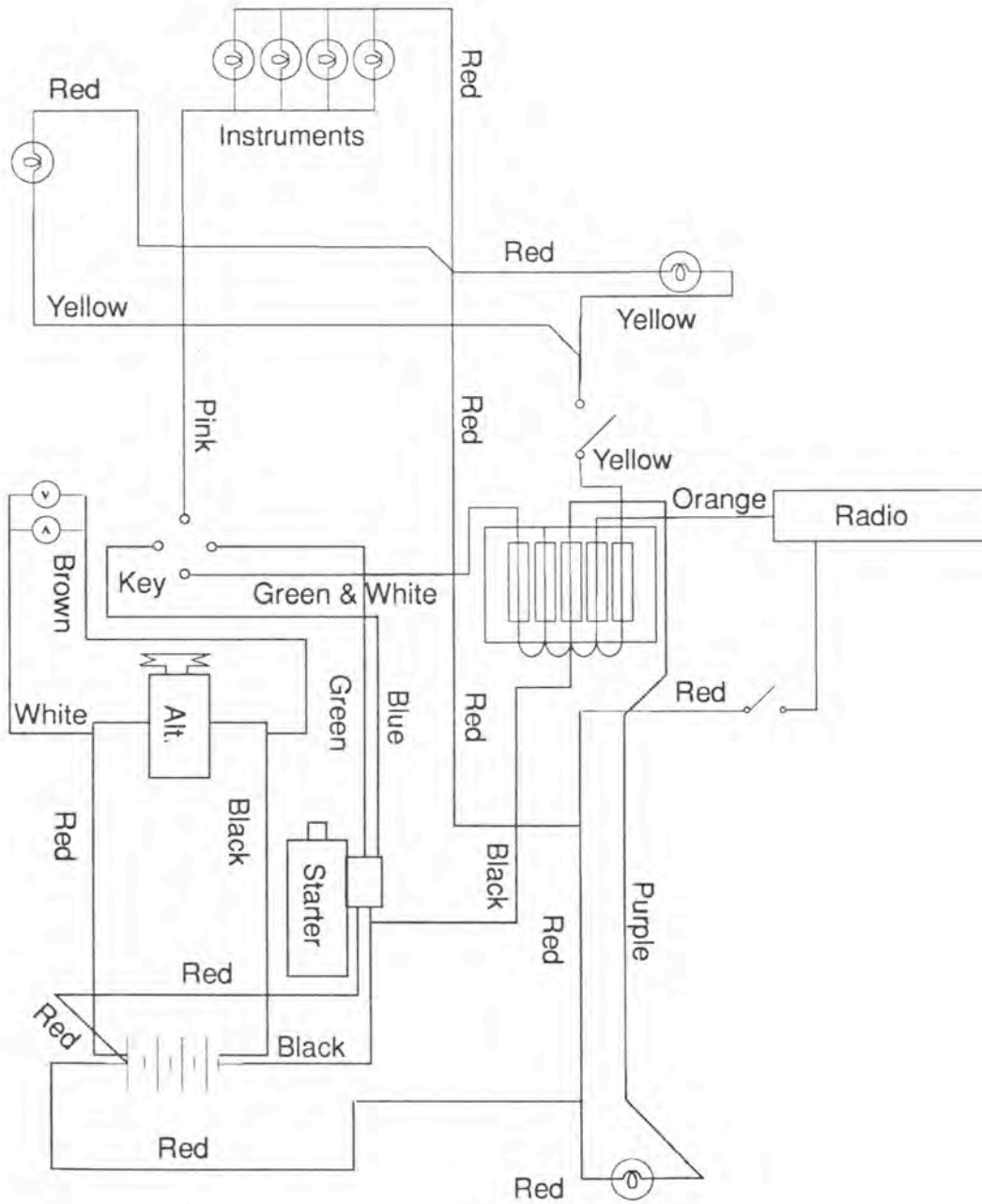
4. (a) No.

(b) All the time.



5. There is no return wire from the starboard light. The radio only works with both switches closed. The radio only works when the navigation lights are on, and only the port light will work.

6. See text.
7. Starter motor.
8. Take out the toilet or cabin light to replace it. It is more important to have navigation lights than internal lights.
9. Try the three amp, but expect it to blow. DON'T use the 10 amp.
10. Poor battery connection; flat battery; poor solenoid connection.
- 11.



# Index

## Symbols

12V battery 8

## A

alternator 15

alternators 13

ammeter 7

amperes 7

amps 7

amps 8

Answers to Exercise 1 24

Answers to Exercise 2 24

atom 5

Atomic Structure 5

## B

background static 15

battery 9

## C

conductors 5

Current 7

## D

depth sounders 16

## E

electrical circuits 7

electrons 5

exercise 1 11

exercise 2 21

## F

fuses 7

## M

marine radio 8

marine radios 15

## N

non-conductors 5

## P

port lights 10

## R

radar 17

radios and related problems 16

## S

satellite navigation 17

solenoids 20

starboard lights 10

starter motors 18

Symbols 6

## V

voltage 8

voltmeter 15

