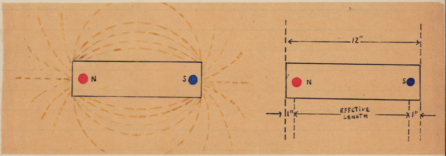
Section One
Elementary magnetism.

Properties of a magnet.

1. Magnets may be "natural" or "artificial" depending on whether they are found occurring naturaly or whether they are magnetised in some artificial way.

2. If a bar magnet is dipped into iron filings, the filings adhere in two clusters near the ends. This leads to the supposition that the magnetism is concentrated at each end of the bar. These points of concentration are called the "Poles" of the magnet, each being approximately 1/12 th. of the length of the magnet from each end. The distance between the "Poles" is known as the "Effective Length" of the magnet.



3. A freely suspended magnet will always align itself in the same direction relative to the Earth, one end pointing approximately to geographic North, the other to South. Since the same

pole points always to the North, it is known as the "North seeking pole", the other as the "South seeking pole" (Known as the "Red" and "Blue" poles respectively).

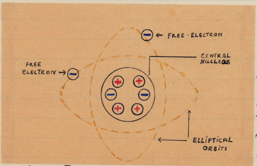
4. If two red (or two blue) poles are placed near together they repel each other, whilst a Red pole will attract an adjacent Blue pole. Thus:-

Like poles repel, unlike poles attract, each other.

5. It is impossible to have an isolated Red or Blue pole, i.e. one cannot exist without the other. This will be explained later.

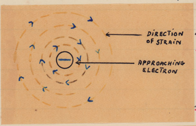
Molecular theory of magnetism.

The theory of magnetism is closely connected with the Atomic and Molecular theory of matter. The atom which is electrically neutral is made up of an equal number of positively charged particles (Protons) and negatively charged particles (Electrons). It consists of a nucleus of protons and electrons with more protons than electrons, the remaining free electrons rotating at high speed in elliptical orbits around the central nucleus.



The whole is analogous to a miniature solar system, distances apart between nucleous and free electrons is immense compared with their own size. The medium between is known as the aether and the force known as magnetism owes its origin to the movement of the free electrons through the aether.

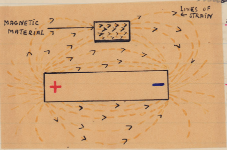
As the electron moves, the disturbance it creates takes the form of „Strain lines" or „Lines of force" and which are roughly concentric about its path.



These strain lines have certain properties which are;

1. The direction of strain is clockwise about the path of an approaching electron.

2. Individual lines are continuous and unbroken.

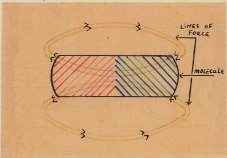


3. Elastic and continuously trying to shorten themselves.

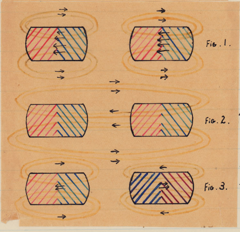
4. Two adjacent lines straining in opposite directions tend to combine; if straining in the same direction tend to repel each other.

5. Pass easily through magnetic materials and will distort to do this.

In certain substances the path of the free electrons extend outside the atom, such substances are magnetic. The smallest possible particles of such substances which can exist separately are known as molecules and are a combination of a number of atoms. Each molecule is surrounded by lines of force due to the atoms it contains, straining as shown, forming a „Magnetic Field" around the molecule giving the molecule „ Polarity".



The pole from which the lines flow is known as the North Seeking (Red) Pole and that into which they flow as the South Seeking (Blue) Pole. The whole molecule forms a „ Magnet".



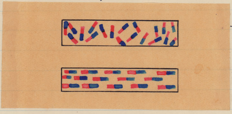
Law of Attraction and repulsion Explained on Molecular Theory.

1. Fig. Red and Blue poles of molecules are adjacent, and the adjacent lines of force are straining in opposite directions. They therefore tend to combine with result that continuous lines of force pass through both molecular magnet as shown in fig. 2. In tending to shorten themselves the lines of force try to draw the molecular magnets together, that is a force of attraction exists between them.

3 Fig. Two Red poles are adjacent and adjacent lines of force are straining in the same direction. They tend therefore to repel each other and are thus crushed together in the space between the molecules

they resist this direction and tend to force the molecules apart; that is a force of repulsion exists between them.

All magnetic matter is supposed to be composed of molecular magnets, and when the material is in the unmagnetised state, the molecules are lying in such positions that they form closed magnetic chains having no external field. When the material becomes magnetised, the molecules are disturbed from

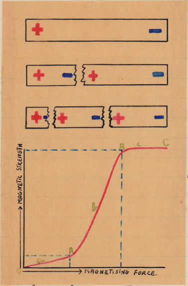


the closed chains and rearranged so that all lie in one direction, red poles pointing to one end and blue poles to the other. It will be noticed that the effect of the adjacent red and blue poles along the length of the magnet neutralise each other leaving a preponderance of blue poles at one end and of red poles at the other end, thus giving the magnet polarity.

This theory is the most satisfactory one yet put forward and is supported by several facts;-

1. If a magnet is broken it is found that the pieces have developed red and blue poles of their own and no matter how far this breaking is pursued, or how small the resulting pieces, this is always the case. If this breaking up is continued it can be carried on until numerous magnets are obtained each of which is molecule. This also leads to the supposition that red and blue poles are

inseparable and that one can not exist without the other.



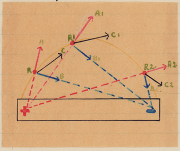
2. „Magnetic Saturation" strongly supports this theory. If the graph of the „strength of the magnet" is plotted against the corresponding magnetising force producing it, the graph obtained is diagram. The curve consists of three phases:-(a) OA, (b) AB, and (c) BC.

During phase (a) magnetising force is largely absorbed in breaking down the closed magnetic chains, and very little alignment of molecules takes place, with therefore, correspondingly small increase in the resulting magnetic strength of the material. During phase (b) the resistance of the closed chains is finally and almost simultaneously broken down, alignment of molecules virtually completed with consequent large increase in magnetic strength for small increase of magnetising force. During phase (c) future increase in magnetising force aligns few remaining molecules and graph becomes straight lines parallel to horizontal axis. At this point the magnetic material is said to be „saturated" and no further increase in magnetising force, however large, produces any further increase in magnetic strength of material.

Magnetic fields.

A magnetic field may be defined as that region surrounding a magnet throughout which its influence may be detected.

At every point in a magnetic field, "a single magnetic pole" will experience a force on it in some definite direction and if the pole were free to move, it would move in the direction of that force. It is impossible to obtain a free pole, but suppose one could and study its behaviour in various parts of the field.



The red pole R will experience a repulsion denoted by the vector RA. and an attraction denoted by RB. the resultant RC. will indicate the direction of the field at that point. In this position RA exceeds RB since R is nearer N then S.

As soon as the pole R moves relative to N and S the components RA. and RB. will have a different direction and magnitude with a corresponding change of the resultant RC. If a number of positions of R were taken it would be found that the resultant would be tangents to a curve. This curve indicates the direction of the magnetic line of force.

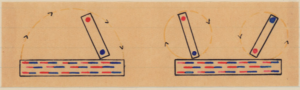
Methods of magnetisation.

1. Hammering in a North-South line. Hammering loosens the molecules, breaking up the closed magnetic chains, thus allowing the molecules to be

aligned in the direction of the Earths magnetic fields.

2. Heating and allowing to cool in a North-South line. Heating also loosens the molecules, breaking up the chains, the molecules set themselves along the direction of the field and are held in alignment when the bar cools.

3. Stroking with another magnet either single or divided touch. The pole of the stroking magnet attracts the opposite poles of the molecules aligning them as it moves across.



4. Electro Magnetic induction (Solenoid). The field created by the current flowing can be made so strong that it breaks up the chains and aligns the molecules.

Method of de-magnetisation.

1. Store two magnets with the like poles together and across the earth's field.

2. Hammer whilst the magnet is lying across the earth's field.

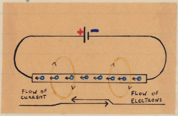
3. Heat the magnet and allow to cool whilst lying across the earth's field.

4. By placing in the influence of an alternating current whilst lying across the earth's field.

Of these four methods the last is most efficient and is used in „wiping" aircraft's parts to remove magnetism.

Magnetic effects of electric current in a wire.

When a wire is connected across an electric supply there is a drift of electrons which flow from the negative connection towards the positive.



Thus around this flow of electrons will be strain lines, clockwise around the path of approaching electron as shown.

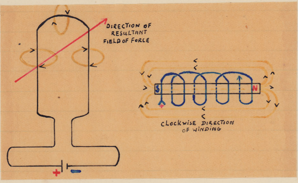
It is more usual to talk of the direction of flow of current rather than of electrons but the conventional idea is that current flows from positive to negative, i.e. opposite to the flow of electrons. Thus the strain lines are around the wire, clockwise in the direction of the current.

There are several rules for remembering the direction of strain around a current carrying wire two of which are given below:-

1. Clockwise Rule – looking along the direction in which the current is passing the direction of force is clockwise.
2. Maxwell's Corkscrew Rule – Imagine a corkscrew being screwed in the direction of the current, the rotation of the thumb indicates the direction of the lines of force.

Consider now a loop carrying a current the lines of force all have their centre on the wire and all flow clockwise about the direction of the flow of current, thus at the centre they will all flow in one direction, in the case shown they will flow into the paper.

Considering a solenoid, the field at the centre of every single coil will be in the same direction and so the lines of strain will emanate from the solenoid as from a bar magnet as shown.



Magnetic measurements - C.G.S. Units.

Dyne. That force which acting on a mass of one gramme would give it an acceleration of one cm/per sec/per sec.

Unit Magnetic Pole. Where two exactly similar poles one centimetre apart in air repel each other with a force of one Dyne, each is said to be a Unit pole.

Pole strength. The pole strength of a magnet is the number of Unit poles contained in the pole.

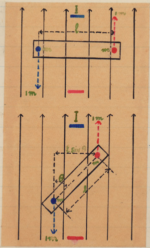
Intensity of magnetic field. If a unit poles is placed at different points in a magnetic field it will experience different forces. Thus we say that the field varies in strength or intensity. If a Pole of strength „m" is placed in a field of intensity „I" the force on the pole will be „Im" dynes.

Unit of Intensity. If a unit ~~of one~~ pole is placed at a point in a field such that it is acted upon by a force of one Dynes, then the field at that point is said to be of Unit intensity. The unit of intensity is the „ Gauss".

Magnetic moment.

The magnetic moment is the measure of the tendency to turn or to be turned by another magnet. It is the product of the pole strength of the magnet and the distance between the poles (effective length of the magnet) and is expressed in centimetre dynes. It is also the couple required to hold a magnet at right angles to a field of unit intensity. If the pole strength of the magnet is „m" and the effective length „l" the magnetic moment is „ml" centimetre dynes. It is usually denoted by „M".

Magnetic Couple.



Magnetic couple equals intensity of field times magnetic moment, equals „I" times „ml" and as „ml" is equal to „M", equals „IM".

Now consider a magnet making an angle of θ with the direction of the field.

Couple = "Iml" sin. θ = "IM" sin θ

(a) If $\theta = 90°$ sin. $\theta = 1$.

Therefore couple = "IM".

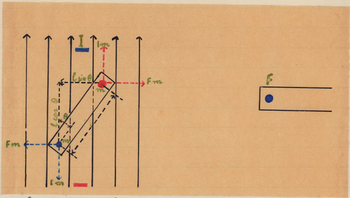
(b) If $\theta = 0°$ sin. $\theta = 0$.

Therefore couple = Nil

Therefore couple is maximum when θ is 90°, i.e. when the magnet is at right angles to direction of field, and if the magnet is parallel with the field there is no magnetic couple.

Effect on a magnet of a deflecting magnet.

Consider a magnet affected by the earth's field „ I" and the field „ F" of a deflecting magnet.



Couple due to 'I' = 'Iml' sin θ

Couple due to 'F' = 'Fml' cos θ

Since the magnet is in equilibrium:–

$$'Iml' \sin.\theta = 'Fml' \cos.\theta \text{ and}$$

$$'I' \sin.\theta = 'F' \cos.\theta$$

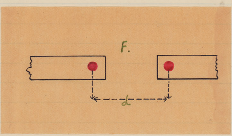
so $F = \frac{I' \sin.\theta}{\cos.\theta}$

since 'I' remains constant (at the same locality) it can therefore be said that 'F' is proportional to tan. θ and for small angles 'F' is proportional to θ.

Note: The forces due to 'F' on each pole are considered to be parallel and opposite since the deflected magnet is small compared with the distance from the deflecting magnet.

Inverse Square law.

This law states that the force acting between two point magnetic pole varies inversely as the square of their distance apart. This holds good both for attraction and repulsion.



From Inverse square law. 'F' is proportional to $\frac{1}{d^2}$

Therefore
$$'F' = \frac{K_1}{d^2}$$

where 'K' is some constant, and 'K' = 'Fd^2'.

Similarly if the distance be varied to 'd_1', the new force of repulsion would be 'F_1' and again

$$F_1 = \frac{K}{d_1^2} \quad \text{therefore } K = F_1 d_1^2.$$

As 'K' = Fd^2 and also $F_1 d_1^2$ therefore

$$Fd^2 = F_1 d_1^2 \text{ or } \frac{F}{F_1} = \frac{d_1^2}{d^2}$$

From the previous paragraph where 'F' is the force on each pole, 'F' is proportional to tan. θ.

Therefore.
$$\frac{\tan\theta}{\tan\theta_1} = \frac{F}{F_1} = \frac{d_1^2}{d^2}$$

i.e.
$$\frac{\tan\theta}{\tan\theta_1} = \frac{d_1^2}{d^2}$$

For small angles tan. $\theta = \theta$ (where θ is measured in radians)

therefore.
$$\frac{\tan\theta}{\tan\theta_1} = \frac{\theta}{\theta_1}$$

i.e.
$$\frac{\theta}{\theta_1} = \frac{d_1^2}{d^2}$$

or
$$\frac{\text{old deflection}}{\text{new deflation}} = \frac{\text{new distance}^2}{\text{old distance}^2}$$

Example.

If the compass of an aircraft placed 10 feet from an end of a hangar is deflected 5°.

(a) What would be the deflection when the compass is 20 feet from the end of the hanger, and
(b) How far away must it be placed to give negligable deviation (of say $\frac{1}{2}^{0}$)?

(a) $$\frac{\text{Old deflection}}{\text{New deflection}} = \frac{\text{New distance}^2}{\text{Old distance}^2}$$

$$\frac{5^{0}}{x} = \frac{20^2}{10^2}$$

$$\frac{5^{0}}{x} = \frac{400}{100}$$

$4x = 5^{0}$ $x = 1\frac{1}{4}^{0}$

Deflection at 20 feet would therefore be $1\frac{1}{4}^{0}$

$$\frac{5^{0}}{\frac{1}{2}^{0}} = \frac{x^2}{10^2}$$

$$\frac{1}{2}x^2 = 500$$

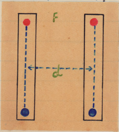
$$x^2 = 1000$$

$$x = \sqrt{1000} = 31.62 \text{ feet.}$$

Therefore compass must be placed approximately 32 feet from the end of the hanger so that only negligible deviation is caused.

Inverse cube law.

This law states that when both poles of magnet are acting on another magnet the force is inversely proportional too the cube of the distance between their centres.



'F' is proportional to $\frac{1}{d^3}$

By the same reasoning as the inverse square law:—

$$\frac{F_1}{F_2} = \frac{d_2^3}{d_1^3}$$

Since $F_1 = K \tan. \theta_1$ and $F_2 = K \tan \theta_2$ $\frac{K \tan \theta_1}{K \tan \theta_2} = \frac{d_2^3}{d_1^3}$ or for small angles $\frac{\theta_1}{\theta_2} = \frac{d_2^3}{d_1^3}$

which again $= \frac{\text{Old deflection}}{\text{New deflection}} = \frac{\text{New distance}^3}{\text{Old distance}^3}$

Example.

A machine gun placed in the starboard wing of an aircraft at a distance of four feet from the compass causes a deviation of $-3°$.

(a) What deviation will it produce if it were placed in the port wing at a distance of 6 feet and

(b) How far away in either wing must the gun be placed so as to produce only $\frac{1}{2}°$ deviation.

(a) $\frac{\text{Old deflection}}{\text{New deflection}} = \frac{\text{New distance}^3}{\text{Old distance}^3}$

i.e. $\frac{3°}{x} = \frac{6^3}{4^3}$

$\frac{3°}{x} = \frac{216}{64}$

$\frac{3°}{x} = \frac{27}{8}$

$27x = 24°$

$x = \frac{8°}{9} = \text{approx. } 1°$

Since it produces $-3°$ when in the starboard wing it will produce $+3°$ at the same distance in the port wing.

Therefore a 6 feet in the port wing the deviation produced would be approximately 1°.

(b) $\frac{3^\circ}{\frac{1}{2}^\circ} = \frac{x^3}{4^3}$

$\frac{1}{2}x^3 = 192$ feet

$x^3 = 384$ feet

$x = 7.268$ feet or approx. 7'3".

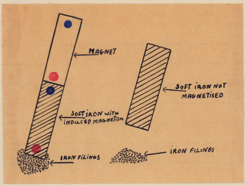
Therefore if placed 7'3" away the compass in either wing the machine gun would cause only ½° deviation.

Hard and soft iron.

Iron and steel may be termed hard and soft in relation to their magnetic properties, as distinct from their physical properties, though it is usually found that a hard metal physically possesses hard iron magnetic properties and vice versa for soft iron.

It is found that hard iron are very difficult to magnetise, but once magnetised they are difficult to demagnetise; i.e. permanet magnets are produced when such metals are magnetised. Soft irons are easily magnetised but when the magnetising force is removed the irons loose their magnetism very quickly; i.e. they provide only temporary magnets.

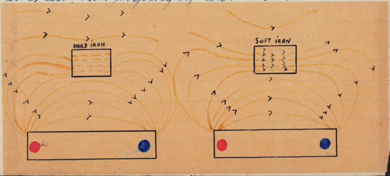
(see diagram following page.)



It would appear from the molecular theory that in case of hard irons the molecules are very closely knit and a powerful force is required to break up their arrangement whether in the closed chains of an unmagnetised rod or the alignment of a magnetised rod. I soft irons the molecules are not so closely knit and are easily aligned and equally easily form themselves into closed chains by mutual attraction for each other when under no external field.

Permeability.

The tendency of magnetic material when placed in a field, is to draw lines of force from the field through itself since it offers an easier path than does air. This property of the material is called



permeability. Soft iron is more permeable than hard iron since it collects more lines of force.

Section two.

Terrestial magnetism.

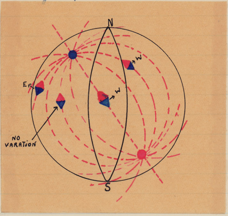
The earth may be regarded as a huge bar magnet so that its field may be detected at all points on its surface and in the layer of space surrounding the earth, but obviously its intensity will decrease in height above the earth's surface. At 50.000 feet it is ⅛ the value on the surface. The earth's field is not so regular as that of a bar magnet, the irregularity being due to the different physical and magnetic properties of the constituents of the earth's crust.

Variation.

The magnetic poles do not coincide with the geographic poles, nor are they at the opposite ends of an axis. North magnetic pole is in Baffin Land, 70 degrees North, 96 degrees West, and South magnetic pole in Victoria Land 72 degrees South, 135 degrees East). The poles are not points but large areas. This displacement of the poles gives rise to Variation which may be defined as:-

The angle measured in horizontal plane between the direction taken up by a freely suspended magnetic needle influenced only by the earth's field, and the direction of the True Meridian at that point.

The following diagram shows the reason for the change of Variation with the geographical position.



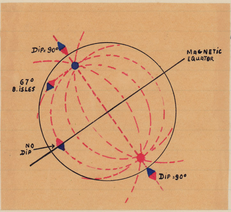
As well as this geographical change of Variation there is also an annual (secular) and a diurnal change, the latter is thought to be due to Cosmic Radiation. The annual change is due to the fact that the magnetic poles are not stationary, but move round the geographic poles, the North pole going round from West to East, and making one complete revolution in 960 years, giving a present annual change of approximately eleven minutes. The figures for London illustrating this annual change are given on the next page.

Figures for London illustrating annual change of Variation are

1580	– 11¼ degrees East
1659	– 0 degrees
1823	– 24 degrees West
1935	– 11½ degrees West

Magnetic Charts have been compiled to show the Variation at any point on the earth's surface. Places of equal Variation are joined by lines called Isogonals and by places of no Variation by Agonic lines.

Dip.



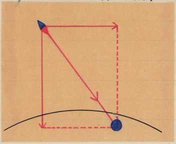
Since the magnetic poles of the earth are below the surface, a freely suspended magnet would not everywhere be horizontal relative to the earth's surface, but come to rest as shown in the diagram. The magnetic needle will point vertically downwards at the poles, where as at the magnetic Equator, it will be horizontal to the earth's surface; at intermediate points it will make an angle between 0 degrees and 90 degrees with the earth's surface (67 degrees in England). This angle is called the angle of „dip" and is defined as:

„The angle measured in the vertical plane between the horizontal and the direction taken up by a freely suspended magnetic needle, influenced only by the earth's magnetic field."

Magnetic charts have been compiled with places of <u>equal dip</u> joined by lines known as „<u>isoclinals</u>" and as these isoclinals are approximately parallel to the parallel of latitude, they are often referred to as „lines of magnetic latitude".

Earth's magnetic field.

From the direction taken up by the freely suspended needle we see that the earth's field is directed towards the magnetic poles in both the horizontal and vertical planes. That is as well as pointing North, it also dips towards North.



From fig.

$\frac{Z}{H} = \tan.\theta$

$Z = I \sin.\theta = I \cos.(90-\theta)$

$H = I \cos.\theta$

The line of total force or intensity is denoted by "I". We can split this force "I" into two components, one "H" in the ~~vertical~~ horizontal plane, and "Z" in the vertical plane. From the figure $\frac{Z}{H}$ equal $\tan \theta$ (Dip).

Section three.

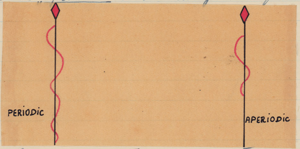
Principles of magnetic compass.

Magnet system.

The three essential of the Compass magnet system are

1. Must cling tenaciously to the direction of the horizontal component of the earth's field (magnetic meridian) and if it is disturbed from this direction, it must tend strongly to resume its original position. To the achieve this, the magnet system must have a large magnetic moment. (ml).
2. It must be able to stop quickly along the direction of the earth's field once it has been displaced - that is,

must be „aperiodic" or without period of swing.



To achieve aperiodicity, magnet system must have small moment of inertia which is done by having

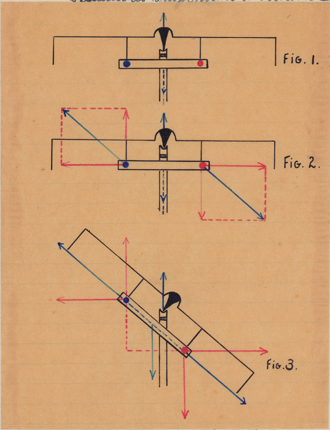
(a). Light magnet system (moment of inertia proportionate to weight).

(b). Having a number of short magnets situated near the centre of the system rather than one long one (decreases fly wheel effect).

(c). By damping, a number of damping wires are attached to the system, which is immersed in suitable liquid. A further effect of the liquid, due to flotation to apparently decrease weight of system, therefore to decrease wear on pivot point and decrease further the amount of inertia.

3. When suspended, the magnet system must remain horizontal. This is achieved by the pendulous suspension of the system (that is, having centre of gravity below point of suspension).

Pendulous suspension to overcome Dip.



It has already been seen that a freely suspended magnet or compass needle will not only point in the horizontal pla[ne] to the North, but will also dip downwards in the vertical plane until lying along the earth's line of total magnetic force, when it will be in equilibrium.

It will be appreciated that since the magnet system in the compass is freely suspended, it will also behave in this way and will be useless for steering a course. Therefore method of bringing it back to the horizontal must be devised.

Early compasses were simply counterweighted on the South end to restore them to level, but obviously this will only work in the one belt of latitude where the compass is made. The method employed now to restore the compass magnetic system to the horizontal is to make the system pendulous, that is, the centre of Gravity is arranged to be below the point of suspension as shown in diagrams one or two.

Now let us suppose the compass needle has actually become tilted due to dip as in figure three. It is seen from the diagram that the centre of Gravity has been moved from below the point of pivot and is displaced towards the South. When this happens, the weight (W) acting at the centre of Gravity downwards, and the reaction (R equals W) acting upwards trought the pivot point form a couple Wd^2 this couple, acting together with small couple Hd^3, in the opposite direction to the upsetting couple Zd_1 therefore, are ~~the~~ restoring couples. It is arranged in the construction of the system that:-

$$Zd_1 = Wd_2 + Hd_3$$

When the magnet system is almost at the horizontal, where it remains in equilibrium.

With increased tilt, d_1 decreases, and d_2 and d_3 increases therefore the restoring couples are greater and return the system to equilibrium. In these latitudes, this state of equilibrium exists when the system is tilted two degrees North end down. The angle of tilt for

This state of equilibrium varies from 0 degrees at the magnetic equator to a maximum at the Poles. In latitudes greater than 70 degrees North or 70 degrees South (Tilt 3 degrees) Z is so great that the compensation due to pendulosity cannot cope, and the compass does not function efficiently.

Compass damping liquids.

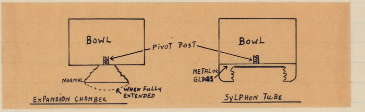
There are certain properties that the ideal liquid must possess:–

1. Cheap and easily obtainable
2. Transparent, so that the compass card may easily be read
3. A large range of temperature at least -50° Centigrade to +50°C
4. A low coefficient of expansion, for since the bowl is completely filled, there must be some expansion device which is not too cumbersome.
5. Low viscosity and specific gravity, or damping will be too great.
6. Must not attack bowl or magnet system.

The liquid is 100 per cent pure Methyl Alcohol, which has to be double distilled to remove all water and impurities, and de-aerated before bowl is sealed.

In the tropics, a little distilled water is added to raise the boiling point. This liquid fulfills requirements 1, 2, 3, and 5, but as regards 4, its coefficient of expansion is rather high, (12 per cent of the volume over the range or temperature met). As regards 6, it attacks black paint and rubber gasket, and forms a sediment which causes pivot friction.

Expansion devices.



There are two types of expansion devices, as shown above, viz. the expansion chamber and the sylphon tube each of which has its own particular merits and demerits, these being outlined as follows:-

The Expansion Chamber.

(a) is rather clumsy, but allows greater expasion of liquid.

(b) is liable to damage if removed from case.

(c) is used on the larger types, e.g. O2 and P4.

The Sylphon Tube

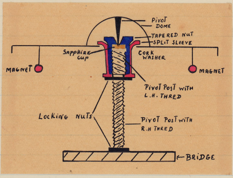
(a) is neat and compact, but cannot cope with such large expansions.

(b) is not liable to damage when compass bowls are out of cases.

(c) the plate at the top of the tube can be made of glass, which permits illumination to be made at night, as in the O6 or by fitting a mirror below the bowl the compass can be used as a vertical reading instrument as in P7. & P9.

Retention of magnetic system In inverted flight.

In order that the magnet system does not become dislodged when the aircraft is inverted, it is necessary to devise some retaining mechanism which will not impair the directional properties of the needle in normal flight. This is illustrated in the following diagram, the mechanism being known as the split sleeve:-



Across the bottom of the bowl is a strip of metal known as the bridge carrying a small brass pillar which is threaded left hand at the top and right hand at the bottom. On the top of the pillar is placed a cork washer on the top of which lies the sapphire cup, the two being held on by means of a tapered nut screwed down on the left hand thread.

The plate carrying the dome of the magnet system forms a lip as shown and if something can be introduced behind the lip so that in normal flight it does not touch it but catches on it when the compass is inverted then the magnet system will not fall out of position.

To attain this a split sleeve is pushed up over the tapered nut so that it will enter the same of the system and once inside it is expanded so that it will retaint this position. Therefore if the compass is inverted the magnet system will rise slightly from the pivot and will be retained, and as soon as the aircraft returns to an even keel, the system will fall into its original position.

The suspension of the bowl.

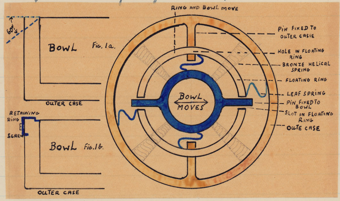
Vibration of the compass bowl will tend to damage the pivot and so, to avoid vibration from the aircraft, it is necessary to support the bowl on its casing by some form of springing. There are certain conditions required in the suspension of the compass bowl:—

1. The bowl must be free to move in any linear direction.

2. It must not in any circumstances be able to turn in azimuth.

3. Earlier compasses had the bowl support on sponge rubber pads but these tended to be over-rigid and were liable to rot and generally deteriorate. On the latest compasses, the bowl is supported on four small helical springs (bronze) resting on lugs on the bowl, and on the outer case as shown on next page.

Diagram showing suspension of bowl.



Although gives a good suspension, and shock absorption, the movement will tend to be somewhat out of control and the bowl will be able to turn in azimuth. A shock absorber must, therefore, be incorporated between the case and the bowl and at the same time, in order to prevent bowl movement, a floating ring is introduced preventing movement in azimuth. This is achieved by means of the floating ring illustrated in Fig. 2.

Two small pins are fixed to the bowl 180 degrees apart and bearing two slots on the floating ring. The bowl can now move in the floating ring in the direction indicated by the arrows. To damp the movement down slightly, two leaf springs are fixed at right-angles to the pins in the bowl and simply introduce slight friction. Two more pins at right-angles to the first two project from the outer casing and pass through holes in the floating ring.

Thus the ring carrying the bowl with it, will now move in the direction shown. Two more leaf springs are fitted to damp down the movement slightly. From all this, it can be seen that the bowl is now resting on the four helical springs, but is controlled so that it cannot turn in azimuth and its movement in the horizontal plane, in all directions, is damped down and fully controlled.

The bowl is prevented from falling out of the casing when inverted by means of a ring fixed to the outer case which engages the lugs used for holding the bronze helical springs. This is illustrated above in fig. 1.

Types of R.A.F. compasses.

P.4. Standard large type Pilots compass, fitted with an expansion chamber. The magnet system has four magnets.

P.4a. The same as P.4. except that it has bakelite grid ring, floating ring and bowl.

P.6. Small edition of the P.4., but with a sylphon tube and only two magnets.

P.7. Modified P.6. with sylphon tube and glass base, fitted with a mirror beneath and used as a vertical reading compass. Obsolete in the RAF., but used in the Fleet Airn Arm.

P.8. Modified P.6. with bakelite fittings.

P.9. Vertical reading P.8. designed as a cabin roof compass. Somewhat neater than P.7.

O,2. Before R.A.F. astro compass it was the standard type of Observes compass. It is fitted with four

four magnets and corresponds in size to the P.4.
O,6. Small hand bearing compass with two magnets and sylphon tube with a glass base. The handle incorporates a torch for illumination at night.

Serviceability tests for compasses.

1. In open cockpit aircraft, inspect the bowl and outer casing for petrol and oil stains.
2. Examine the liquid for discolouration.
3. Examine the liquid for bubbles, and see that the verge glass is not cracked.
4. Examine all parts concerned for luminosity of paint.

Mechanical tests.

1. Ensure that the grid ring rotates freely through 360 degrees and that the locking device works correctly.
2. On "O" type compasses, ensure that the sights are all secure and that the prism is unscratched.
3. Test the suspension of the bowl by moving it slowly in all direction, ensuring that there is no metal feeling.

Magnetic Tests.

1. Test for pivot friction. Deflect the needle 10 degrees to 15 degrees and allow it to return, noting the reading. Repeat in the opposite direction and the two readings should be 2 degrees of each other. For practical purpose gentle tapping is allowed.
2. Test for damping. Deflect the needle through 90 degrees. Hold for 30 seconds to allow it to settle, and time its swing back through the first 85 degrees. The maximum times for this are laid down in the instrument manual

e.g. for the P.6. 6.5 to 8.5 seconds.

Installation care and maintenance of compasses.

Care and maintenance.

1. Always handle carefully, as shocks will damage the pivot.
2. Always store upright, so that the magnet system is free to revolve and take up its natural line.
3. Never store near electrical apparatus, or in a strong magnetic field.
4. Alway keep "O" type compasses in their box or correct storage positions, when not in use. They should never be left on their mountings.
5. Never force the grid ring or the azimuth circle around or strain the locking device.
6. Compasses should be periodically inspected by a competent officer to ensure that they are fully serviceable and correctly maintained.

Installation.

1. Ensure that the holding down bolts are of non magnetic material.
2. Ensure that no part of the aircraft, other than the mounting plate is touching the compass.
3. Ensure that when bolted down, the compass is truly in the horizontal plane of the aircraft.
4. Ensure as near as possible that the lubber line is truly in the fore and aft axis of the aircraft or parallel to it.

Times when a compass should be swung.

1. When a new aircraft is accepted be the R.A.F.
2. When a new compass is fitted as a replacement to

another.

3. With any change of magnetic material within the aircraft (e.g. engines).

4. After a major inspection.

5. After any great change of latitude.

6. After flying through a magnetic storm.

7. After standing on one heading for more than 4 weeks.

8. Once a month or at least every 8 weeks.

9. At any time at the discretion of the C.O. or when the accuracy of the instrument is in doubt.

Section four.

Elementary aircraft magnetism.

I has already been explained that one of the methods of making a magnet is to hammer in the N.S. line or by heating the material and allowing it to cool in N.S. line. Both these processes are ultilised in the construction of aircraft parts. From this it will be realised that these parts will become magnetised in this manner. Although some of the magnetism is removed by wiping the individual parts there will always be some residual magnetism. When the aircraft leaves the factory on its first flight, an additional part of this magnetism will be lost due to vibration etc., but that which remains is more or less permanent throught the life of the aircraft, with the same polarity and the same strength. Some slight change however is liable to occur under extreme conditions namely:—

1. Aircraft struck by lightning.

2. Severe electrical storm.
3. Very heavy landing.
4. Major modification (engine change etc.).

There will be enumerable magnetised hard iron parts in the aircraft quite a number of which will be sufficiently near the compass position to have an effect upon it. Suppose now that we could resolve these parts into one hard iron magnetic bar which will have the same effect on the compass. The total force on the compass due to this rod can be split up into three components, one in the fore and aft axis, one in the athwartships and one vertical.

In actual fact the splitting up of the force at compass position due to the aircrafts magnetic field, into three components mutually at right angles along the axis of the aircraft is theoretically done to facilitate the analysis and correction of its deviating effect on the compass needle.

The compass needle will tend to align itself along the tangent to the line of force of the field at the compass position. The force on the needle therefore due to aircraft magnetism can be split into three components two in horizontal plane of the aircraft (fore and aft and athwarships) and one in the vertical plane. Suitable combinations of these components can produce a single force in any direction and of any magnitude. This force on the needle at the compass position is composed of the three components, P force and aft, Q athwartships R, vertical.

There are termed positives or negatives according

These are termed positives or negatives according to whether they attract the Red end of the compass needle forward starboard or vertically downwards (positive or +). If they attract the Red end aft, port or vertically upwards (negative or –).

Component R acting vertically has until quite recently been small enough to be ignored but now on certain types of aircraft having a considerable depth of fuselage and a fairly acute angle in the tail down position its effect can no longer be ignored and vertical correctors have had to be employed (e.g. Hudsons and Venturas).

Soft iron effects.

Besides the hard iron parts of an aircraft materials are used which have soft iron magnetic properties. These soft iron parts will become magnetised by:–

a. The permanent magnetism of the hard iron parts of the aircraft structure.
b. The earth's magnetic field.
c. Any other extraneous influences apart from a and b, e.g. hangars, runways cables etc.

The magnetism induce in the soft iron by the permanent magnetism of the aircraft hard iron parts remains constant so long as the permanent magnetism itself remains constant, and is indistiguisble from it. The magnetism induced in the soft iron parts by this means, ~~that~~ has therefore the same effect as the permanent magnetism and should be understood to be included with it. The extraneous influences should not be present when the compass is being swung or in use.

The numerous pieces of soft iron distributed about the aircraft will depend for their magnetism upon the earth's field, thus their position relative to the earth's field will determine their polarity and also their pole strength. (When changing from one hemisphere to another polarity is changed in vertical soft iron).

In order to analyse the effects of soft iron we can resolve each of the soft iron rods into 2 soft iron rods, one Horizontal and one Vertical. The horizontal rod will be magnetised by the horizontal component H and unaffected by the Vertical component Z consequently its magnetism will vary with H i.e. with the heading of the aircraft. The vertical rod will be magnetised by the vertical component Z and unaffected by the horizontal component H, consequently its magnetism will not vary with the aircraft's heading but only with its location (i.e. with Z). Therefore for any particular location the magnetism in the V.S.I. can be considered as quas.-permanent and considered along with the permanent magnetism.

Vertical soft iron.

Considering the vertical rod of our resolved soft iron, it will be magnetised by the vertical components Z of the earth's field only, and therefore the amount of magnetism induced will depend on the aircraft's location alone and not on the heading, i.e. magnetism induced in the V.S.I. rod only varies with the intensity of the earth's vertical field at that particular place. There are various positions in which the rod maybe situated, relative to the compass but whatever it's position maybe it will be in one of the four sectors illustrades in the following diagram.

Consider the rod to be in quadrant I. If the soft iron rod at P is placed so that it's blue pole is nearer the compass position than the Red pole, it's effect on the compass needle would be as from a single Blue pole and there would be a force of attraction between the rod and the Red end of the compass needle, and this force would be acting in the line Bx and could be represented in magnitude and direction by the vector Bx. By completing the parallelogram of forces this single vector Bx can be resolved into two component vectors Bz and By in the athwartships and fore and aft lines respectively. The component in the fore and aft line is known as „c" and that in the athwartships line as „f". The components „c" and „f" are often referred to as „c" and „f" rods i.e. A single rod „P" can be replaced by two rods; one a „c" rod in the fore and aft axis of the aircraft and the other an „f" rod in the athwartships axis. Therefore whatever the situation of the soft iron rod in relation to the compass position, it can split up into two rods whose effect will be exactly the same as the single rod they replace. The convention for the sign of the rods is exactly the same as for the hard iron components „P" & „Q" that is the effect of a Blue pole forward gives a plus „c" and the effect of a Blue pole to starboard gives a plus „f".

It will be realised that whatever the positions of these vertical rods and whether positive or negative, they will combine with „P" and „Q" having either an increasing or decreasing effect on the