Phantom II Head Corrosion

(A Slim Monograph by Barrie Gillings)

INTRODUCTION

HOW THIS BOOKLET CAME TO BE

In recent years, the Registrars of various Registers have arranged for seminars to be held at RROCA Federal Rallies. For the 54th Federal Rally "Ecstasy in Paradise", seminars were conducted for the Pre-war Small Horsepower Register, the Silver Wraith, Silver Dawn, Mk VI and R Type Register and the Derby Phantom Register. Brian Crump, the Registrar for the Derby Phantom Register, asked me to give a talk on aluminium cylinder head corrosion, a subject of considerable concern to me, as my Phantom II has had this problem. Because of my scientific background, I conducted a series of experiments, and did some research, which I thought might be of interest to fellow owners.

A small but enthusiastic group of Phantom owners attended my presentation, and some were sufficiently interested to ask for a digest of it. Brian Crump urged my wife Margaret and me to prepare a booklet covering the subject, and this record of my research, its related physics and chemistry and what I discovered during my cylinder head restoration is the result.

Some readers may feel that the areas I covered are surplus to their requirements, and may be tempted to skim-read them or by-pass them entirely. I urge them to persevere, because a well-informed owner is much less likely to be bamboozled by an opportunistic R-R or B car salesman, or even worse, a hungry 'restoration specialist'.

I have written the areas covered in this booklet in a way which I hope allows understanding without the need for exam-passing skills in Physics I or Chemistry I, so there is no quiz at the end. But if, having read it, you understand that radiator water should be as pure as you can afford, that you should not add ethylene or propylene glycol (unless you live where rivers and creeks freeze) and that anything you do add is simply to suppress corrosion and foaming, this booklet will have achieved its aim.

THE BASIC SCIENCE

## Figure 1 . PERIODIC CHART OF THE ELEMENTS

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Figure 1

The Periodic Table lists the chemical elements according to the number of electrons orbiting their atoms. The first is Hydrogen (H1), which consists of a positively charged Proton, with one negatively charged orbiting Electron. (Fig 1, left). The next is Helium (He2) right, with two protons, and two orbiting electrons. Lithium (Li3) is next, with three protons and three electrons, but its third electron starts a new 'layer' of electrons. Beryllium (Be4) is next with two outer shell electrons. On the right are Boron, Carbon, Nitrogen, Oxygen, Fluorine and Neon, with 3, 4, 5, 6, 7 and 8 outer shell orbiting electrons. It is the matching Protons (and Neutrons) in the atoms that give them weight, and the outer 'layer' of electrons which dictate the element's chemical behaviour. Element 11, Sodium, starts another new layer of eight electrons, and this layer of eight ends with element 18, Argon (A). The next layer can accommodate 18 electrons, starting with 19, Potassium (K), and ending with 36, Krypton (Kr).

The periodic table arranges the elements in recognizable groups, shown here separated by dark lines with the *light* metals on the left, the *inert gases* (which have complete electron layers) on the right, *high melting* metals in the middle, (further separated into *brittle, ductile, noble and low-melting*) and *non-metals* on the right. The 'complete' layers, or 'shells' of orbiting electrons are maximums of two, then eight, eight, eighteen, eighteen and eighteen The chemical and electrical behaviour of elements depends entirely on the behaviour of the outer layer of orbiting electrons, and their weights the number of Protons and Neutrons in their nucleii. Only the outer electrons take part in chemical reactions.

Formation of grains and grain boundaries during solidification from a molten state. Note that developing grains of the same orientation coalesce, but those of mismatched orientation form a grain boundary. (From Samans, C. H.: *Engineering Metals and Their Alloys*. The Macmillan Co., 1956.)
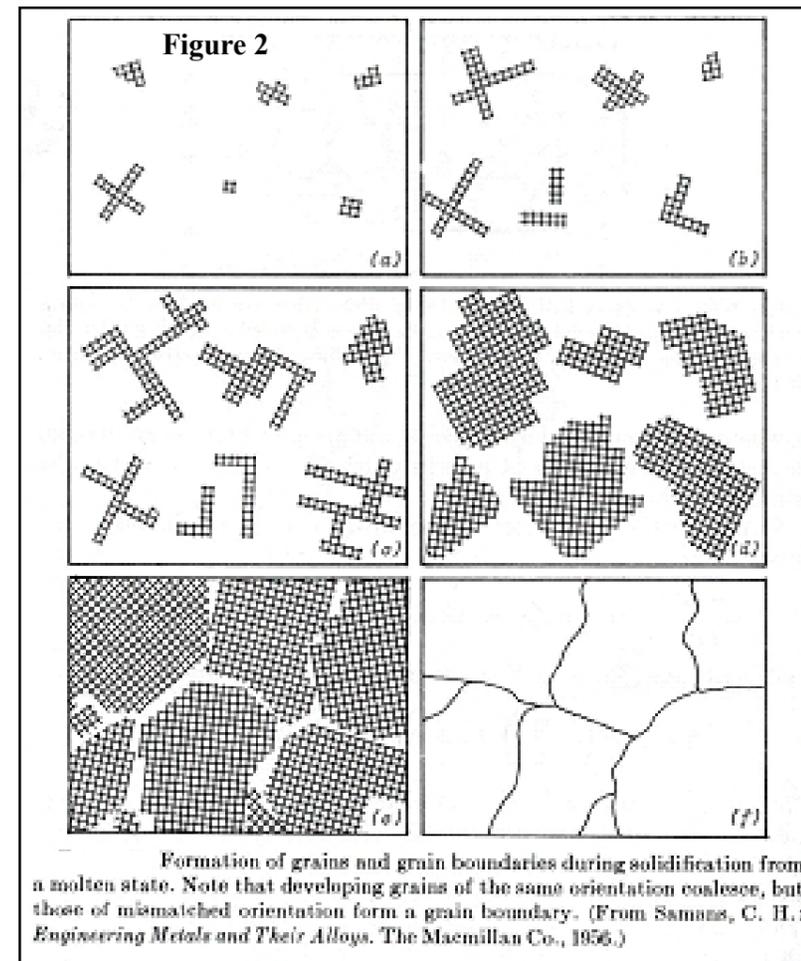
Figure 2 (left)
The atoms of metals are solid at room temperature (except Mercury (Hg)) and arrange themselves, through mutual attraction, in the crystalline patterns of face-centered cubic, body-centered cubic or close-packed hexagonal. Melting destroys these patterns, and when cooling, the atoms re-assemble in their specific crystalline patterns. The individual crystals grow larger as they cool and accumulate more atoms, until eventually they come up against a neighbouring crystal and growth ceases. These interfaces, which are three-dimensional, are called grain boundaries.

Figure 3 (below)
If an appropriate acid is applied to a polished metal surface, the grain boundaries are preferentially etched, and display the grain structure. This technique reveals much about the nature of the metal or alloy, and helps to explain its behaviour.

Figure 3

FIG. 6.16. *a*, schematic representation of mechanically polished surface. *b*, photomicrograph of mechanically polished surface. Note scratches on surfaces and dark spots indicating surface pits and inclusions. *c*, reflection of parallel light on surface after etching. *d*, photomicrograph of etched specimen revealing grains of different orientation and grain boundaries. (From Samans, C. H.: *Engineering Metals and Their Alloys*. The Macmillan Co., 1956.)

Figure 4

Figure 4

The melting points of the copper-nickel alloys

ALLOYS LIQUID
ALLOYS SOLID
ALLOYS PASTY
1454° Nickel melts
1083°C Copper melts
Pure nickel → 0 10 20 30 40 50 60 70 80 90 100 ← Pure copper
Percentage of copper

Figure 4a

EUTECTIC with 62% tin at 183° C
Lead melts at 327° C
Tin melts at 232° C
183°
Pure lead → 0 10 20 30 40 50 60 70 80 90 100 → Pure tin
Percentage of tin
The melting points of the tin-lead alloys

Figure 4

Few metals are used in the pure state because mixtures of them, called alloys, often have superior qualities. For example, bronze, an alloy of copper and tin, is harder and tougher than the parent metals. Metals in alloys almost always have different melting points, so what happens when a molten mixture of two metals is cooled? The graph in Figure 4, upper left, plots temperature (vertical scale) against various mixtures of nickel and copper, from 100% nickel on the left to 100% copper on the right. Above the upper graph line, the alloy is in the molten state, and the below the lower graph line is in the solid state. In the space between the two graph lines the alloy is in a 'mushy' or 'pasty' state, neither solid nor liquid. This type of alloy is termed a 'solid solution'.

Figure 5

ORIGINAL ANNEALED METAL THICKNESS 0.110" NO. 9 B. & S. GA.

COLD ROLLED TO THICKNESS
0.100" NO. 10 B. & S. GA. | 0.090" NO. 11 B. & S. GA. | 0.080" NO. 12 B. & S. GA. | 0.070" NO. 13 B. & S. GA. | 0.060" NO. 14 B. & S. GA.

ANNEALED FOR 30 MINUTES AT 350° C.
ANNEALED FOR 30 MINUTES AT 500° C.
ANNEALED FOR 30 MINUTES AT 650° C.
ANNEALED FOR 30 MINUTES AT 750° C.
ANNEALED FOR 30 MINUTES AT 800° C.

FIGURE 14—5. Grain size of brass (copper 66 per cent, zinc 34 per cent), after cold working and annealing. ×40. (Prepared by L.H. DeWald.)

Figure 4a A different form of alloy is the 'eutectic'. The graph in Figure 4, upper right, plots temperature against various mixtures of 100% lead, on the left, and 100% tin on the right. The graph demonstrates that at one point in the mixture range, the melting point is lower than the melting points of the two components, and such alloys are called 'eutectics'. This alloy of 62% tin and 38% lead is 'electricians' solder', and solidifies quickly and at a lower temperature than either lead or tin.

Figure 5

Grain size shows great variation in different metals and alloys. Figure 5 shows grain size changes after brass is cold-rolled and annealed.

Figure 5a

Cold working | Recovery | Recrystallization | Grain growth

Tensile strength
Ductility
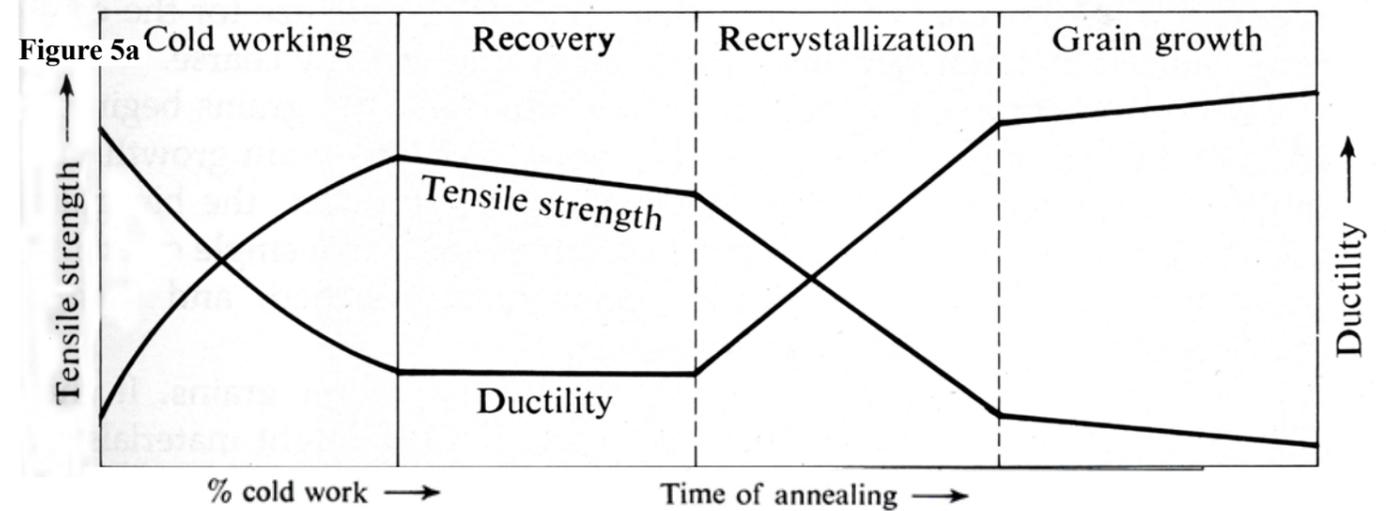
% cold work → Time of annealing →

The tensile strength and ductility of a metal as a function of the per cent of cold work and annealing time. Tensile strength increases and ductility decreases during cold working. These properties change only slightly during recovery. During recrystallization, the tensile strength decreases and the ductility increases rapidly. Only slight changes occur during grain growth. (From Richman, M.H.: Introduction to the Science of Metals. Waltham, MA, Blaisdell Pub. Co., 1967.)

Figure 5a

This demonstrates how the grain size and shape of a metal or alloy can be changed by cold-working and later annealing. Cold-working usually increases hardness and strength but reduces ductility while annealing causes grains to grow and restores ductility, but reduces strength.

Figure 6

Diagram of an electrolytic cell.

External Circuit
V
Anode (+)
Cathode (-)
Electrolyte
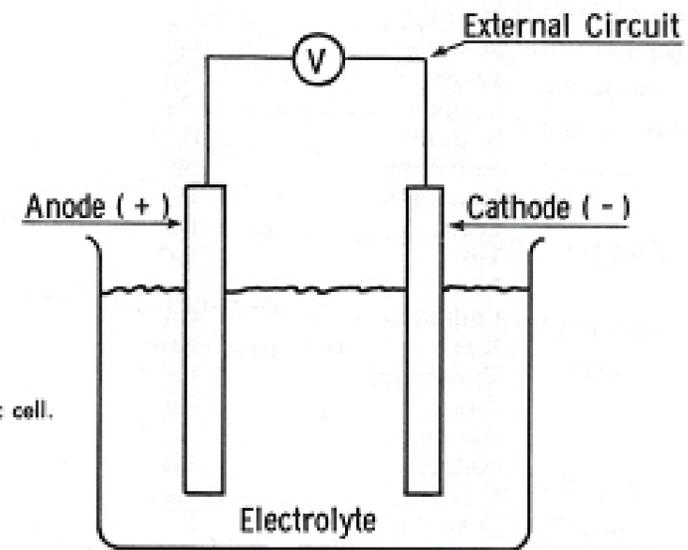
Figure 6

Corrosion occurs in two forms: chemical and galvanic, alone or together. Chemical corrosion occurs when a liquid or gas reacts with a metal surface. Galvanic corrosion occurs when two dissimilar metals are separated by an electrolyte and there is present an electrical current pathway. The freedom with which the outer electrons of the metal or alloy can be released or interact governs the nature of the corrosion.

For the Phantom II cylinder head, the galvanic corrosion is the more destructive. But chemical corrosion does occur, and is most commonly the result of oxygen reacting chemically with the metals of interest. Aluminium, exposed to air, becomes coated with a very adherent and protective coating of aluminium oxide, which can protect against further corrosion. Manufacturers can deliberately induce this oxide formation on aluminium, usually incorporating pigments, in the process of 'anodizing'. Magnesium, zinc, chromium, nickel, titanium, tin and cadmium all form oxides which are, more or less, protective against further corrosion in air, and are self-limiting. Other chemicals in the air such as sulphates, carbonates, sulphides etc. can form somewhat protective coatings, such as the verdigris on copper and bronze.

For the destructive galvanic corrosion to occur, you need an anode, a cathode, an electrolyte and a current pathway, as shown in the diagram. Eliminate any one, and you stop this corrosion. Painting the anode or cathode provides insulation: no current pathway. Cut the contact between anode and cathode, again insulation: no corrosion. Remove the electrolyte (dry the surfaces): no corrosion. In some cases, a deposit of corrosion products on the 'electrode' isolates it from the electrolyte, acting like a coat of paint, and this initial corrosion then progressively prevents further corrosion. Unfortunately, this protection rarely protects the PII cylinder head.

Figure 7 ELECTROMOTIVE SERIES OF THE METALS

METALS	ION	ELECTRODE POTENTIAL (VOLTS)
Gold	Au^+	+1.50
Gold	Au^{+++}	+1.36
Platinum	Pt^{++}	+0.86
Palladium	Pd^{++}	+0.82
Mercury	Hg^{++}	+0.80
Silver	Ag^+	+0.80
Copper	Cu^+	+0.47
Bismuth	Bi^{+++}	+0.23
Antimony	Sb^{+++}	+0.10
Hydrogen	H^+	0.00
Lead	Pb^{++}	−0.12
Tin	Sn^{++}	−0.14
Nickel	Ni^{++}	−0.23
Cadmium	Cd^{++}	−0.40
Iron	Fe^{++}	−0.44
Chromium	Cr^{++}	−0.56
Zinc	Zn^{++}	−0.76
Aluminum	Al^{+++}	−1.70
Sodium	Na^+	−2.71
Calcium	Ca^{++}	−2.87
Potassium	K^+	−2.92

Magnesium Mg++ -2.40

Figure 7
The likelihood of galvanic corrosion can be assessed from the 'electrode potentials' of the metals/alloys involved. These potentials are measured as voltages +/- in comparison with a standard electrode (hydrogen gas bubbled over a platinum electrode), and recorded as the 'electromotive series'. This table records the potentials for a range of elements, (but omits an important one, Magnesium, (-2.4)).

From this table, you might assume that if you have Copper (+0.47 volts) and Zinc (-0.76 volts) in a conducting solution, you have a battery developing 1.23 volts. This is an over-simplification, because surface chemistry is also involved. But in broad terms, if the two metals are joined, the Copper will acquire a surface layer, depending on the electrolyte, and the Zinc will corrode. Likewise, coat Iron (-0.44 volts) with Zinc (-0.76 volts) and immerse them in a conducting solution and the Zinc will corrode preferentially and protect the Iron. This is the rationale of galvanised Iron, with the Zinc protecting the Iron 'galvanically'. Magnesium blocks bolted to outboard motors protect the motors by dissolving preferentially in seawater as a 'sacrificial anode', so you could say that the Phantom II cylinder head aluminium corrodes to protect the iron, nickel, copper, chromium, lead, nickel and cadmium components.

Figure 8   (next page)
An important factor in the corrosion of PII cylinder heads is the nature of the coolant. Any soluble salts (which dissociate into anions (+ve) and cations (-ve)) in the water will make it conductive, thereby promoting electrolytic corrosion. So will any strong acid or alkali, but these may also promote chemical corrosion. So use distilled or de-ionised water, or clean rainwater collected from a tile, plastic or painted (not galvanised iron) roof, in your radiator. Do NOT use tap water, which has dissolved salts, even though it might taste just fine.
It is important that radiator water not be strongly acid or alkaline. You should have a general idea of the acidity
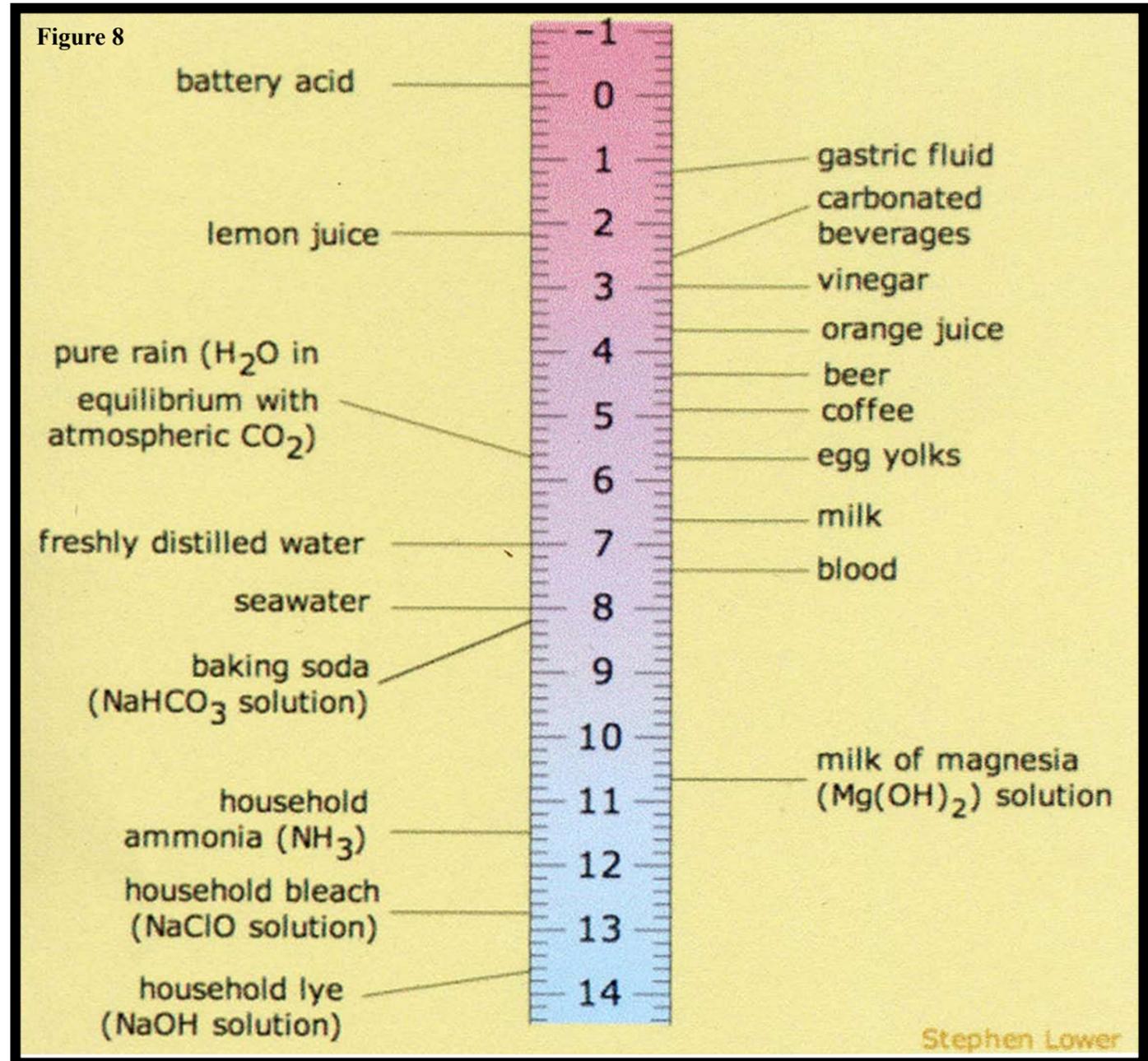

Figure 8 (cont.)

or alkalinity (pH) of your water. pH stands for "the power (p) of the Hydrogen ion (H^+) concentration, and is not too hard to understand. Pure water is two Hydrogen atoms joined to one Oxygen atom, as H_2O. The three atoms are firmly bound as a molecule, but in pure water, one in ten million separates into one Hydrogen ion H+ and one Hydroxyl (Hydrogen/Oxygen) ion OH-. This state is recorded, by convention, as the concentration of the hydrogen ion, one part in ten million, 1 in 10^{-7} which can be expressed as a negative logarithm of the concentration, ie, 10^{-7}, and is called pH7. If you increase the H+ concentration tenfold, by adding, say, a very little hydrochloric acid (H+Cl-) to the water, the pH becomes 6; by 100, pH 5, a thousand; pH 4 and so on until pH 0, when all the solution is pure H+ and Cl-. Likewise, if you increase the OH- concentration by ten, by adding very little caustic soda (Na+OH-) say, to the water, the H+ concentration decreases to 1 in 100 million, or pH 8 and so on.

The pH values for many common solutions are shown in the table, and you will find that most radiator water will be like swimming pool water, say 7.5 to 8.5, especially if you have added commercial coolant additives like Penrite or Water-Wetter. What you do not need in the radiator water is ethylene or propylene glycol. These are excellent wetting agents, and will find even very small leaks in your system. So unless you live above the snow line, in winter, the glycols are not needed. In addition, they are considerably less efficient than pure water in transferring heat from the engine to the radiator.
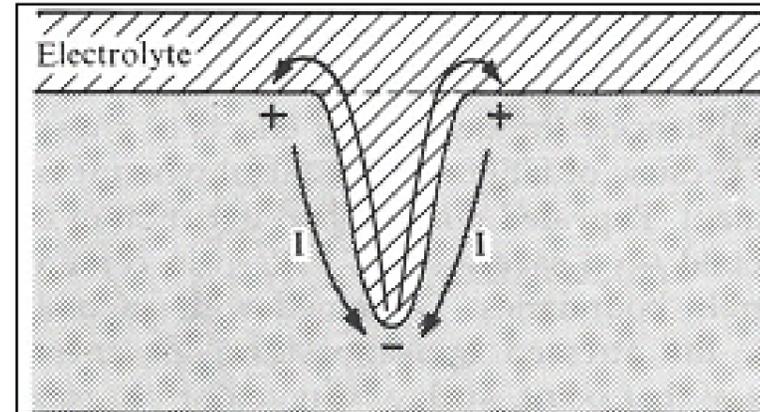
Figure 9

Electrolyte

FIGURE 16—4. A pit is actually a small corrosion cell. The material at the bottom acts as the anode and that around the rim of the pit acts as the cathode. The ionic current flows through the electrolyte and the electronic current through the metal. (With permission from Richman, M. H.: An Introduction to the Science of Metals. Waltham, MA, Blaisdell Pub. Co., 1967.)

Figure 9

Rolls-Royce stressed the need for smooth finishes on its cast or machined metal components. There was a reason for this. If there is a crack (or scratch or pit) on a surface, and the surface is wet with a fluid containing ions, a corrosion cell is formed. The bottom of the crack acts as the anode, and the edges of the crack act as the cathode. An ionic current runs through the electrolyte, and an electric current through the metal. This causes the situation shown in Figure 6. Thus the smoothness of surfaces on, say, a connecting rod has a definite benefit.

There is another, related benefit. Analysis of materials under stress shows a very heavy concentration of these stresses on large scale sharp internal corners and bends. Small scratches, cracks and pits can cause an even greater concentration of stress and possible fracture. A polished surface eliminates this effect.

Figure 10

Figure 10

Here are (l-r) a Phantom II rocker cover, cylinder head, the two blocks, the twelve cylinder block cover-plates, then the front head cover-plate and the fan assembly. These have all been chemically cleaned and bead-blasted. When undertaking a cylinder head restoration, the head chemical cleaning and bead blasting greatly assist in identifying any faults and cracks. These are actual or potential causes of fracture or leakage.

Figure 11
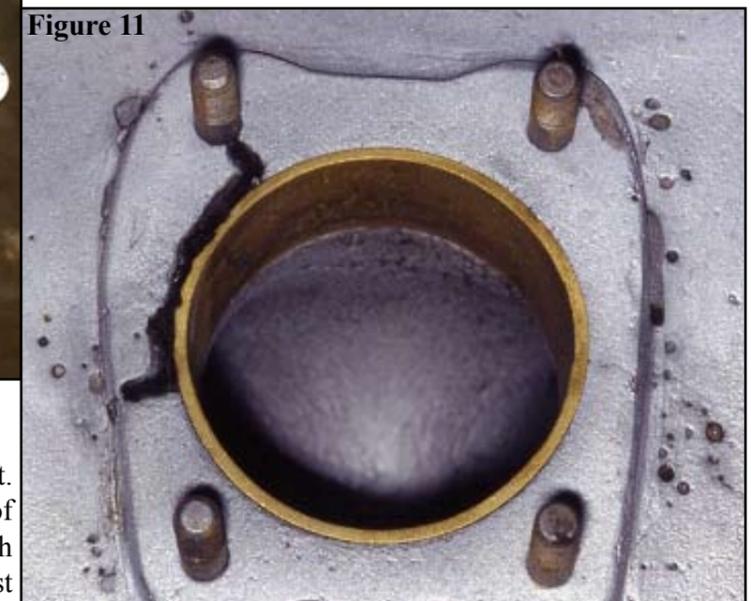
Figure 11

This inlet port was severely corroded on the left. This was probably a result of the close contact of the copper faces of the exhaust manifold gasket with the steel stud, the aluminium of the head and the cast steel of the exhaust manifold. Here a brass sleeve has been fitted to the exhaust port. The corroded aluminium was cut away and replaced with a heat-tolerant metal- filled plastic. The plastic repair has lasted ten years so far, and can be considered to be successful.

Note the round pits on the left and right. These were exposed when sections of the head were replaced, aluminium welded into position and the weld trimmed back. These pits did not leak.

Figure 12

The corrosion cracks in the L and R spark plug recesses are probably the result of deficient welding repairs plus subsequent chemical corrosion. They did not leak. The cracks starting at two of the copper tubes which accommodate push rods are almost certainly electrolytic corrosion. They do not weaken the head, but may leak, as the tubes are sealed into the head by expanding them for a depth of about a centimeter with a tapered drift. (The wooden pegs are to seal head holes to allow for pressure testing.)

After a head has been repaired (welded and shaped), it is wise to chemically clean it, then bead- blast it, examine it for any faults, and correct them. The head should then be dried thoroughly and then immersed in an anaerobic-cure liquid, such as Loctite, perhaps twice. This resin penetrates any small cracks, pits and porosities, and cures in situ because of the absence of air. The surface resin remains unset and is washed off. The process seals off all but the worst leaks. They will show themselves in the pressure test.

Figure 13

This is a large electrolytic corrosion defect caused by the copper push rod tube reacting with the aluminium of the head. It is much too large to be corrected by anaerobic resin, and welding would require removal and replacement of the copper push-rod tube. Here the space has been repaired with metal-filled plastic resin. The much narrower gap between the copper tube and the head aluminium has been filled with anaerobic resin.

Figure 14

This shows a test panel of aluminium, with two sacrificial anodes, (L and R) and, in the middle; at 12 o'clock, a nickel-plated, threaded steel plug; at 3 o'clock, an unplated steel bolt and square nut; at six o'clock, a threaded brass plug,: at nine o'clock, a steel bolt and galvanized steel washer. The hole in the middle of the plate has a copper eyelet peened into place.
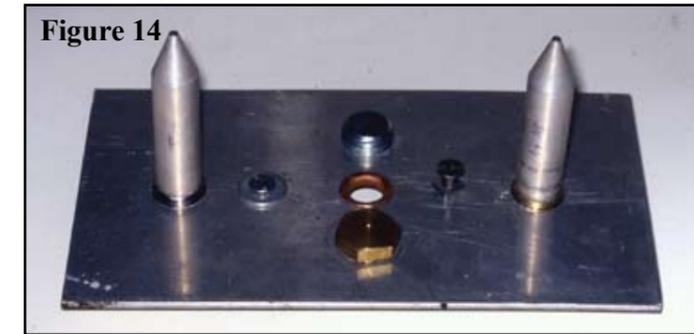
Figure 15

This shows the top view, on the right, of the plate in Fig.14, compared with, on the left, a similar plate with the same combination of metals but without the two sacrificial anodes.

Figure 16

This shows an angle view of the upper surfaces of the two plates after immersion in salted pool water for several months. The unprotected plate (left, no sacrificial anodes) is covered with corrosion spots, probably aluminium oxide or hydroxide. There has been heavy rusting of the nickel-plated steel plug and both the steel bolt and nut, and the steel bolt and galvanised washer have rusted. The threaded brass hexagon plug and the peened copper eyelet are uncorroded. All items show a measure of white aluminium corrosion associated with their contact with the aluminium. The aluminium plate on the right has been completely protected by the sacrificial anodes.

This protection has included all the other items. There has been no rusting at all. There is a white deposit on the steel and copper components, but not on the brass. Two of the sacrificial anodes have indeed sacrificed, and lost perhaps 80% of their magnesium. The middle one is a new anode, fitted to the 6 o'clock brass plug (Fig. 14).
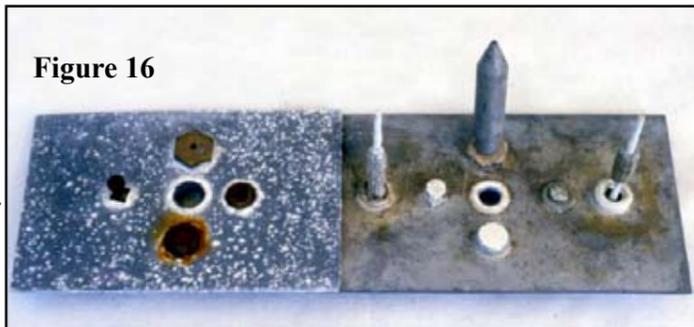
Figure 17

This is the appearance of the underside of the two plates shown in Figure 16. The plate on the left is the unprotected one and exhibits the same type and level of corrosion as its upper surface, which is to be expected. It is due to the salt water and any resultant electrical and chemical reactions between dissimilar metals. On the right, the sacrificial anodes have protected the items,

which are on the **underside** of the plate, in much the same way as they did on the plate's upper surface side. This demonstrates that the form of corrosion protection is electrochemical, and occurs because magnesium (Mg) is more electronegative than, and is the sacrificial anode for all the other metals and alloys in this test.
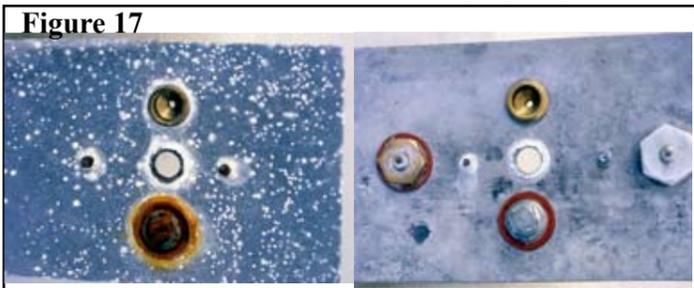
Figure 18

In an experiment conducted to test the feasibility of using sacrificial magnesium anodes to protect the Phantom II cylinder head against internal corrosion, the four welch plugs on the inlet side and the five on the exhaust side were removed and replaced with stainless steel threaded plugs fitted with anodes, as shown in Figure 18. This is their appearance after four weeks of service, using rainwater as the radiator coolant, and no additives. An unused anode (left) is included for comparison. Magnesium loss was greater on the exhaust side, possibly

because the temperature in that area was slightly higher, or because of the presence of the copper push rod tubes. It was a surprise to find that the push rod tubes, when removed, were found to be nickel-plated. This may indicate that R-R thought this would suppress their corrosion to some extent.

Figure 19

Figure 19

From the results of the earlier experiments, it is reasonable to assume that the magnesium anodes would reduce aluminium cylinder head corrosion. It probably did, but there was a significant disadvantage. The corrosion products of the sacrifice, probably magnesium oxide, were sufficient to deposit as a layer on the top copper tubes in the radiator header tank, and impede coolant flow. A simple method of preventing this is to insert a long skein of stainless steel pot scourer material, which traps, very effectively, any particulates in the radiator water, and confines it to the cylinder, head, which is, after all, where it came from. This technique is a more practical version of the sometimes recommended 'filter in the radiator hose', which requires frequent cleaning, or the 'nylon stocking filter', which is difficult to fit and even more difficult to remove for cleaning. It is sobering to remove the front cover of the cylinder head and note the corrosion on the inner surface of the plate.

Figure 20

Figure 20

The advantage of using the stainless steel pot scourer as a filter is that it does not corrode, and offers very little restriction to coolant flow, but still manages to trap even fine particulate matter, as can be seen here. The CD is there for size comparison.
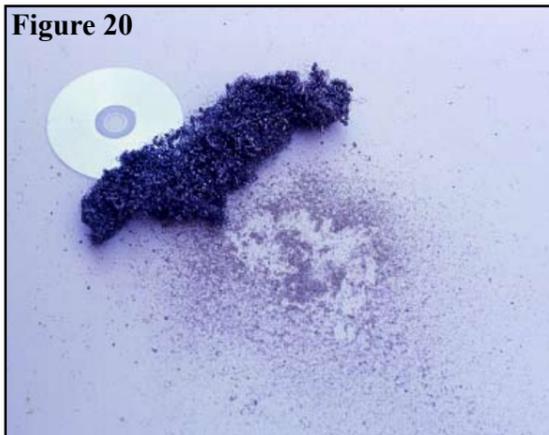

Figure 21

Figure 21

The Phantom II, and possibly other models, has a radiator which has two access plates on the bottom tank. The one on the driver's side is fitted with an elbow, connected to the water pump intake pipe by a hose. The radiator drain cock is attached to this elbow, and has here been fitted with a compressed air hose fitting. A compressed air hose can be connected to this fitting, and allow the operator to blow compressed air into the radiator without removing it from the car.
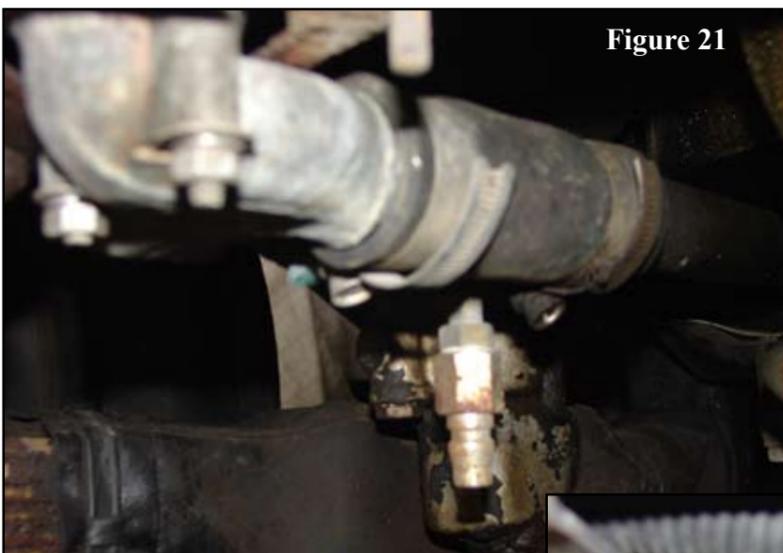
Figure 22

The access plate on the passenger's side of the radiator is blank, but has here been fitted with a simple tap and a standard garden hose click-on fitting. The operator can now back-flush the radiator using tap water, without removing the radiator.
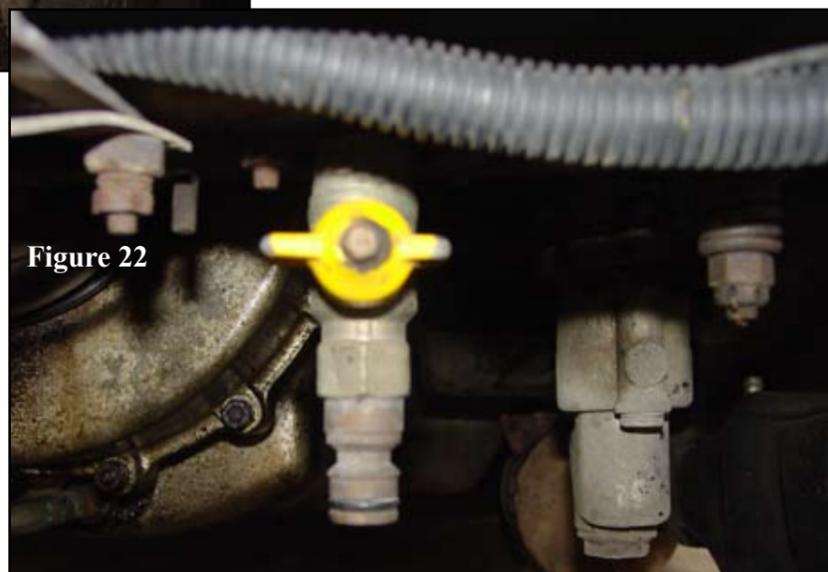

Figure 22

Figure 23

Figure 23

Here you see the back-flushing in progress. It shows the effect of turning on the compressed air after the garden hose has filled the cooling system. The bucket was positioned to collect the ejected water, in order to allow examination of the sludge that was dislodged. The bucket was incorrectly positioned because the force of the water flow was underestimated.

Figure 23a

Figure 23a

This shows the bucket in the correct position to collect the ejecta. If you plan to use this system, it is important to make up a plastic pipe and elbow, and fit it to the radiator filler pipe as shown here to avoid splashing dirty radiator water over the engine and mudguards.
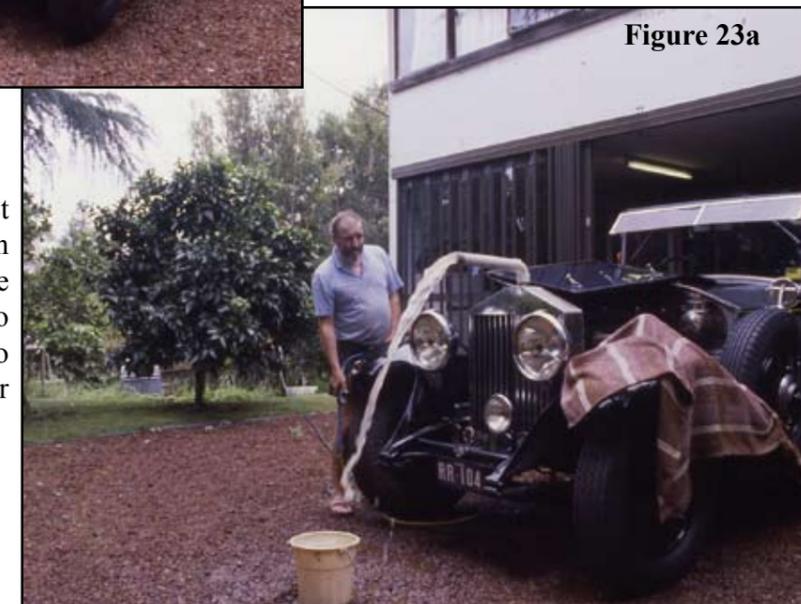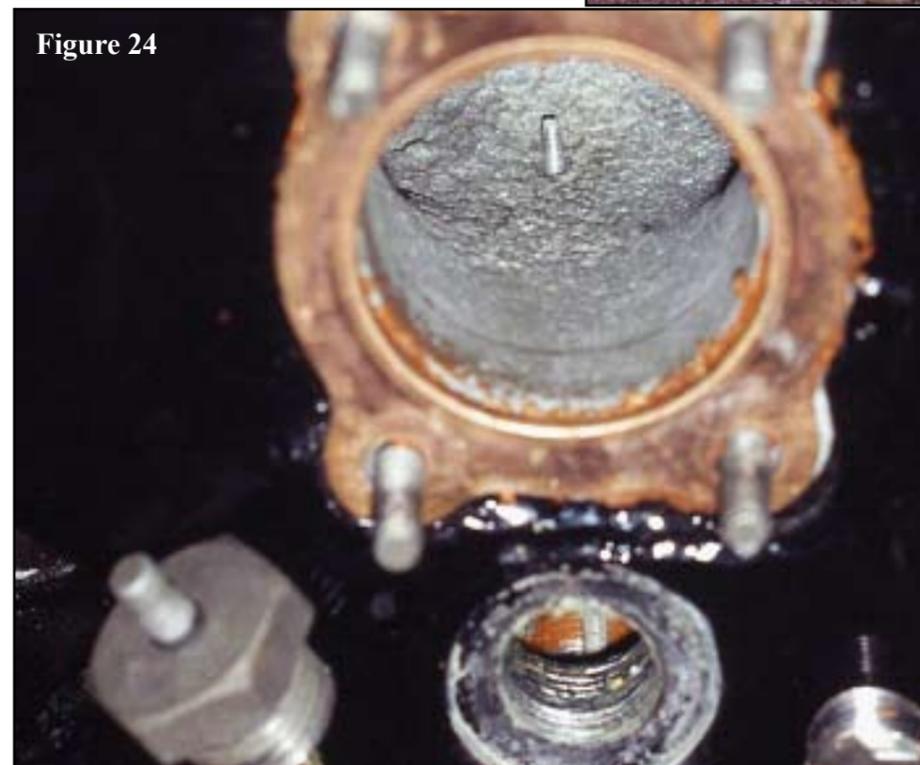
Figure 24

Figure 24

The picture illustrates what can happen if you run your engine with low coolant for any length of time, most frequently a consequence of boiling because of a blocked radiator and coolant loss through the overflow pipes. Head temperatures can rise alarmingly, sometimes so far as to melt the interior of the exhaust ports to produce holes and allow coolant to enter the exhaust system. This will be indicated by water being blown out of the exhaust, as has been the case here. An aluminium wire has been inserted past the welch plug hole and bent upwards to enter the small hole which has appeared in the thinned floor of the exhaust port. This hole must be repaired or the head is useless.
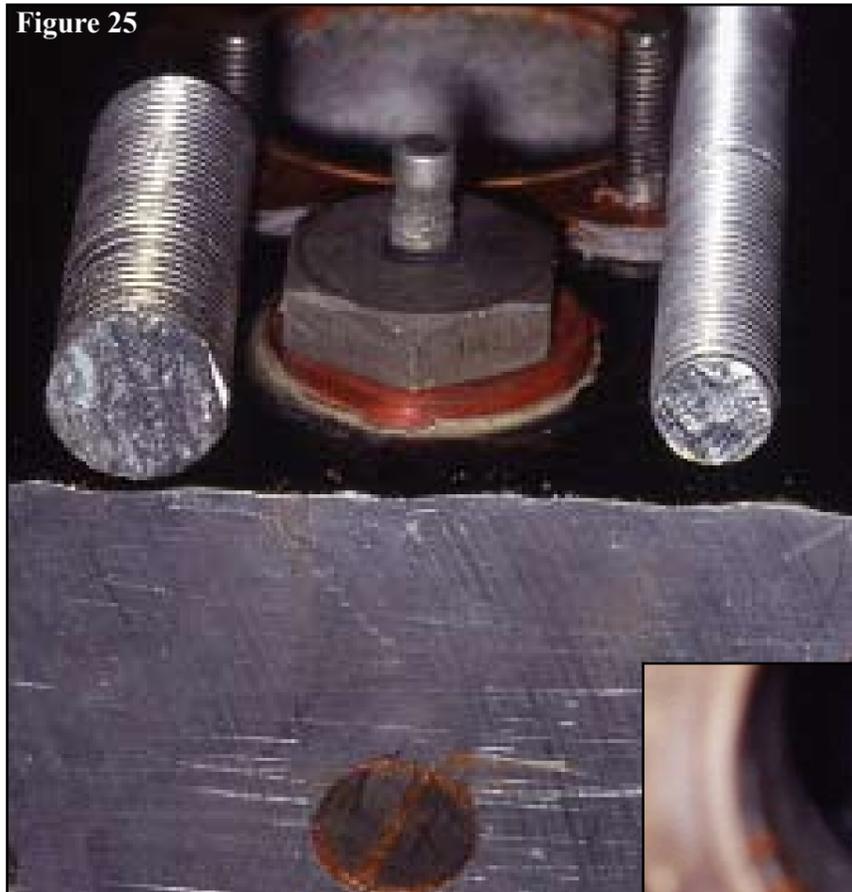
Figure 25

Here two threaded aluminium rods have been used to make repairs to holes. The small rod repairs a hole in the base of the cylinder head. The large rod is threaded through the face of the cylinder head and into the exhaust port. Both rods have been sealed against leaks by high conductivity, heat-resistant copper-impregnated silicone sealant.

The hexagon-headed plug and fibre washer have been screwed into a welch plug hole, and carry a platinum-plated titanium anode (see Fig.27), used as a replacement for the magnesium sacrificial anode. A set of nine such anodes were used in an experimental 'cathodic protection" system.
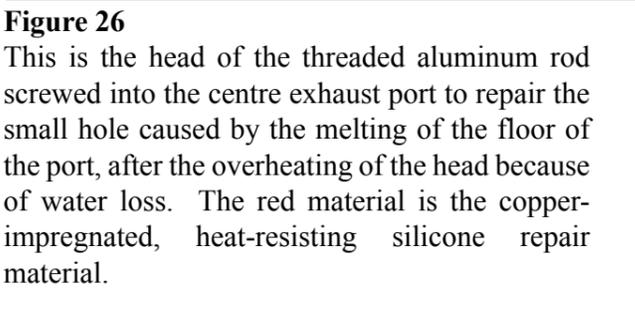
Figure 26

This is the head of the threaded aluminum rod screwed into the centre exhaust port to repair the small hole caused by the melting of the floor of the port, after the overheating of the head because of water loss. The red material is the copper-impregnated, heat-resisting silicone repair material.

Figure 27

Here you see an angle view of the area shown in Figure 25. The welch plug holding the platinum-plated titanium anode is shown, fitted into and insulated from its stainless steel hexagon plug, which screws into the threaded welch plug hole. Platinised titanium anodes can replace sacrificial magnesium anodes when a small direct current is applied to them. In effect, they reverse the effect of electrolytic corrosion. This system is used on most large ships, and on buried tanks and gas and water pipelines everywhere.

Note also the threaded plug (right and also in Fig.25) which screws into and repairs a hole in the head face. Projecting through the hole is the other end of the aluminium wire seen in Figure 24.
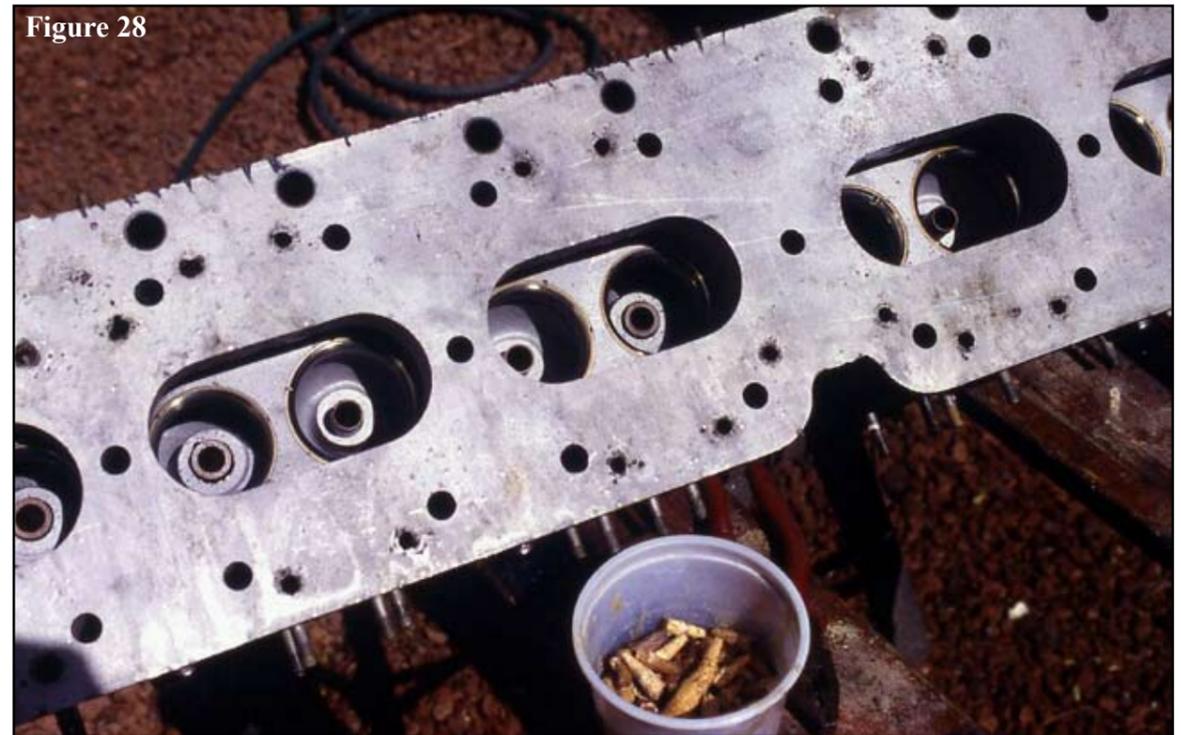
Figure 28

When the cylinder head has been repaired, it must be tested for leaks before fitting. To do this, all holes in the head which connect the inside of the head to the outside must be blocked. This requires the use of many softwood plugs, shaped and tapped carefully into the holes.

Figure 29

The PII cylinder head is very heavy, and the use of a willing assistant is most helpful for the next process, which is pressure-testing. A water source is required, and is connected to the otherwise sealed head by a hose connected to a small reservoir, here held above his head by James Kelso OAM. This provides very little pressure, here about 15 kPa. But this pressure is probably sufficient for most folk, as the cooling system of the Phantom II is not pressurized. That is to say, it is open to the air in the header tank, unlike modern cars, which usually have a sealing radiator cap which puts the coolant under a pressure of 10 or so kPa when the engine is running.
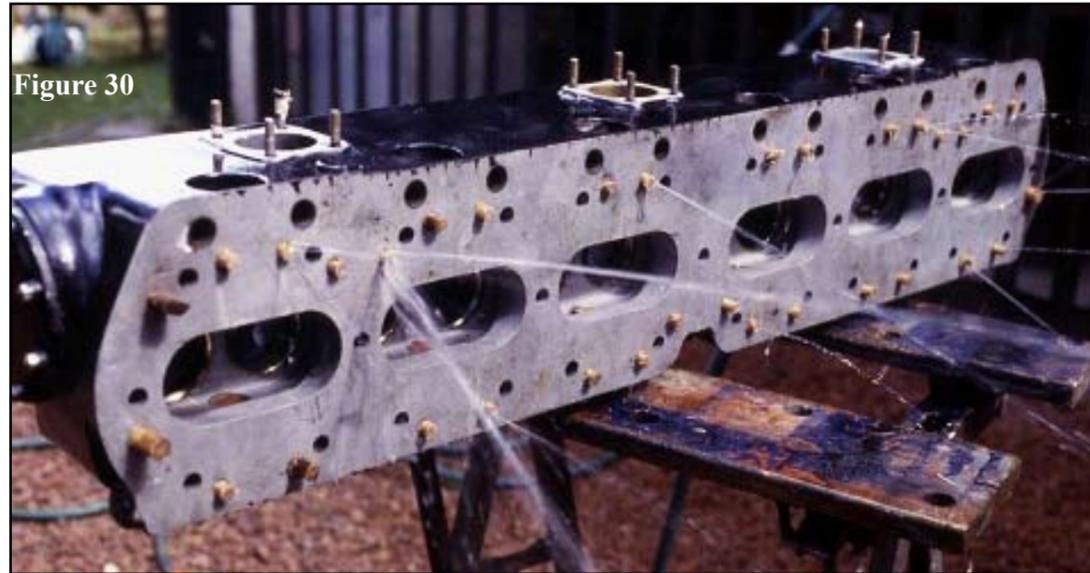
Figure 30

Cylinder head pressure testing does not require the use of an adjustable pressure regulator. It is a simple matter to arrange for an accurate and controllable water pressure for head-testing. On the ground below the cylinder head there is a three-way hose connection. One hose is attached to an inlet connection to the cylinder head (the temperature gauge opening). The second hose is attached to a water tap. The third is attached to a hose which is open-ended and can be elevated to a height of, say, five meters. When the tap is turned on, the water fills the cylinder head, then rises in the hose to five meters, then overflows. This head of water, adjustable by raising or lowering the hose, establishes a pressure of about 10 kPa per metre of hose-end height above the cylinder head. If no head leaks appear with three metres or so of height, the head is sound, and should not leak in service. The photograph shows that some of the wooden plugs did not seal effectively but that was because the holes were not very round as they were corroded. However, the head itself did not leak, and that was reassuring.


Figure 31

Here you see two more willing assistants, Lyel Murrell (l) and Chris Gillings (r) fitting the completed head to Phantom II 147GN. This head was chemically cleaned, given a porosity-sealing treatment, the valves were ground and the valve seats lapped. After ten years of service, a slight unevenness at idle and an occasional 'huff' from the exhaust pipe prompted a compression test, which revealed only 160 kPa on two cylinders, instead of 640 kPa for the remaining four. When the head was removed, all seats showed some valve seat recession, but two were inoperable. This situation has now been corrected, and PII 147GN (Mona) has now been restored to her previous good health.

WHAT SHOULD YOU PUT IN YOUR RADIATOR?

Your radiator is there for one reason: to remove excess heat from your engine while it is running. As the following pages explain, the very best substance you can put in your radiator is water. All other liquids are less efficient at transferring heat. So far as corrosion is concerned, chemically pure water, distilled and de-ionised, is best, as it will not cause chemical or electrolytic corrosion. But it will not stay pure for long. Air will be whipped into it, react with the various metals in the engine, and, in time, the water will contain various ions, and these will accelerate corrosion.

So it is wise to add a corrosion-inhibiter to your radiator water. Modern cars are designed with a sealed, pressurised cooling system and the manufacturers usually recommend the use of glycol-based coolants. These 'coolants' are all you can buy at the average auto supply shop. Most of them also contain corrosion inhibitors, and the only reason for adding them to your non-pressurised 'open system' radiator is to get this corrosion protection. Some specialized suppliers, such as Penrite, make corrosion-protection additives which do NOT contain any glycol. These stand-alone additives work very well in our cars.

Corrosion protection additives are of two basic types, IAT and OAT, which stand for Inorganic Acid Technology and Organic Acid Technology. Examples of the former are: sodium silicate, disodium phosphate, sodium molybdate and sodium borate, and the latter are: carboxylates of various types. The manufacturers do not usually reveal what type of corrosion inhibitor(s) their products contain, which is yet another reason for not using them.

COOLANTS

Figure 32

Table 1
Thermal Properties of Cooling System Materials

Material	Density g/cm³	Thermal Conductivity Watt/m · °C	Thermal Convection Watt/m · °C	Heat Capacity cal/g · °C	Heat of Vaporization cal/g
Water	1.000	0.60	1829	1.000	539
Glycol	1.114	0.25	------	0.573	226
50/50	1.059	0.41	897	0.836	374
Aluminum	2.70	155		0.225	
Cast Iron	7.25	58		0.119	
Copper	8.93	384		0.093	
Brass	8.40	113		0.091	
Ceramics		1 - 10			
Air	.0013	.026		0.240	

Figure 32

It is a common misconception that the products sold as automotive coolants are superior to plain water as a means of keeping a car engine cool and happy. An internal combustion engine is a 'heat' engine, and the energy delivered to the wheels depends on the expansion of the gasses in the cylinders caused by the heat of combustion. Thus, the hotter the engine, the more expansion and the more energy delivered. The car's thermostat is designed to keep the working temperature high, but not so high that the coolant boils and causes other problems. The engine's coolant is circulated through the engine to transfer heat, evenly, from the cylinders to the radiator, but the engine needs to be kept hot, in the interests of fuel efficiency. With our pre-1940 Phantoms, there is a lot of heat to be collected and transferred to the air passing through the radiator. Furthermore, the design of the engines can leave local 'hot spots' where the water actually boils, but goes 'off the boil' before reaching the radiator. In addition, internal corrosion over the years insulates the internal surfaces and slows down the heat transfer from the metal to the coolant.

The late John McFarlane of fond memory, (Editor for 25 years of 'The Flying Lady', RROC USA's magazine) had a memorable quote explaining this effect:

"Phantom, Phantom, boil and bubble; Chop the crud and cure the trouble".

Owners will know that some cars of the same model are susceptible to boiling. There are many reasons for this, but one of them is the inappropriate use of proprietary coolants. The table in Figure 32 compares the thermal behaviour of water, ethylene glycol and a 50/50 mixture of them. The first column compares density, which is similar and unimportant. The second compares the ability to conduct heat, and it is clear that water does this twice as well as glycol. This quality is reflected in water's ability to transfer heat through convection, again twice as efficient as a 50/50 mixture of water and glycol. But it is the ability of water to contain heat (and thus transfer it) that is really outstanding. Water can hold twice the heat of glycol, and is in fact, the best of ALL substances, gram for gram, in holding and transferring heat. Even better, water's heat of vaporization is more than double that of glycol. This means that it absorbs more than twice the heat of glycol before boiling.

So why do cars use glycol-based coolants? In cold countries, it is essential, because water expands quite a lot when it freezes, and when it does, it can crack cylinder heads and burst radiators. But it not only lowers the temperature at which the coolant freezes, it also raises the temperature at which the coolant boils, which permits a higher operating temperature and better efficiency without the danger of boiling. In addition, most coolants contain additives which suppress corrosion, and it is probably this quality that prompts Phantom owners to use commercial coolants. But the anti-freeze quality is unnecessary for Australian cars, except those that inhabit very cold parts.

This Table also records the thermal conductivity of the metals used in our Phantom engines. The Phantom I cast iron head has about one third of the conductivity of the aluminium head of the Phantom II and Phantom III, and also the small H.P. cars with aluminium cylinder heads.

Figure 33

The Silver Ghost Association is a club exclusively for Silver Ghosts, and has a world-wide membership of 550, 60% in the USA and 40% in other countries, with about 15% (81) in the UK and 14% (75) in Australia. The Club magazine, 'The Silver Ghost Tourer' often carries well-researched technical articles, and Issue 2011, No 3 has a comprehensive assessment of coolants by Bill Kennedy (p 2104-2112). Because it was written primarily for the US members, it covers US coolants, and probably all of them mentioned contain glycol. Bill identified 26 which use IAT (inorganic acid technology) additives and 40 which contain OAT (organic acid technology) additives, to control engine corrosion and scale. He stresses that the OAT types are formulated for modern engines, with modern metals, including aluminium radiators. He says the OAT additives attack copper, lead and tin, and should not be used in R-Rs which have these metals in their cooling systems.

There is a simple additive that can be added to the radiator water of pre-1940 R-Rs which causes no harm and assists in reducing water loss. For reasons not known to the writer, his PII sometimes had a froth on top of the water in the radiator, and when present, the water level was usually low. He deduced that the froth being generated was slowly blowing bubbles down the two overflow tubes, and causing a minor but nonetheless worrying water loss on long runs. This loss was completely eliminated by adding a small amount of an anti-foaming agent (e.g. No-Foam) used in spas and hot tubs.

But a significant discovery was the availability of a coolant additive called Water Wetter. Lancia Lambda owners have a very serious cylinder head and block problem, the designs of which greatly restrict coolant flow to the front of the head, causing overheating, local boiling, distortion and cracking. The localised boiling produces steam, which is a good insulator, and this further hinders cooling. Water wetter is claimed to facilitate transfer of heat from such hotspots and also prevent boiling. The claim has been tested in a regularly-driven Lancia, examined by engineer William Smith after three annual changes of Water Wetter. The side plates of the engine were removed and the head and block interior surfaces examined. They were a dull grey, completely free of corrosion and had the appearance of being passivated. It was also noted that the engine ran cooler with Water Wetter than with plain water.

The author has noted that his PII engine runs several degrees cooler with Water Wetter, and the radiator shutters can now be used the way the handbook suggests. After nearly a year of service, the coolant appears only slightly cloudy, suggesting that any corrosion has been minimal. Reports from other R-R owners who have used the product support these observations. The Water Wetter website shows corrosion test figures which are well below the ASTM (American Society for Testing and Materials) D1384 minimums.

Figure 33

Figure 34

Removal of Heat from Aluminum @ 304°F
Beginning Coolant Temperature 214°F

100% Glycol
Boiling Point 50% Glycol @ 15 psig
50% Glycol / 50% Water
Boiling Point Red Line + Water @ 15 psig
50 / 50 with WaterWetter™
Water
Water Treated With WaterWetter™

(Aluminum Block Temperature, °F vs Seconds)

Figure 33

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REFERENCE MATERIAL

Many sources were used to provide the information cited in this booklet. They may not be readily accessible to the non-academic reader, but are included to acknowledge the information they provided, and to guide the reader who has a thirst for more technical information. The sources are listed by the page or pages involved.

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