NOTES ON THE WATER-CLOCK by E.S. Nurse.

The operation of the home-made, pendulum-controlled water-driven clock can be understood by any intelligent child who inspects it closely for a minute or two. The whole of the parts are clearly visible.

The following notes cover most of the points that would be likely to be of interest to people who, having watched the clock, want to know more of the details. They are divided into sections as follows:-

I	-	The origin of the idea of the clock
II	-	The limitations of the clock
III	-	Some technical details
IV	-	Instructions for operation & maintenance.

SECTION I - THE ORIGIN OF THE IDEA OF THE CLOCK

The creator of the clock is a retired Naval engineer whose main hobby is mechanical gadgetry in a fairly wide range of applications, mainly concerned with the home. A self-imposed restriction in making such gadgets is that they must be made of commonly available materials and by the use of simple hand-tools and an electric soldering-iron (though a small arc-welder is used for things requiring any considerable strength).

This self-imposed restriction on materials and equipment obviously places a corresponding restriction on the design of gadgets since it precludes the use of finely machined parts to accurate dimensions; there can be no precision in the fits of bearings; and to get sufficient accuracy in the alignment of bearings the bearing supports must be capable of bending or other adjustment.

On the other hand the restrictions have the beneficial effect of making it very important to consider all sorts of possible designs, including the most unorthodox, in order to discover a simple design which can be made by hand.

In considering a design for a clock the possibility of using a strong spring or heavy weight driving the clock through a train of wheels and an escapement mechanism had to be ruled out as it was impossible to make the wheel train and escapement. In the search for an alternative means of giving the pendulum a constant and gentle push each swing, the idea of using drops of water was finally hit upon, and a simple experiment sufficed to show that the pendulum itself could carry out the function of escapement. It then remained to provide a small but reasonably constant supply of water to drive the clock and a simple means whereby the pendulum could actuate the second, minute and hour hands.

SECTION II - THE LIMITATIONS OF THE CLOCK

In the first place the time-keeping accuracy of the clock is relatively poor and cannot be relied upon to be better than plus-or-minus about one minute per day. The pendulum is made of galvanised iron wire and there is no compensation for changes in temperature. Also the amplitude of the swing of the pendulum varies with the rate of supply of water and this adds to the errors in time-keeping.

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In the second place a still more serious limitation of the clock on loan to the Science Museum (see note below) is its liability to stoppage due to either over-supply or inadequate supply of water.

Over-supply may be caused by a rise in water temperature. The viscosity of water at 90 deg. F. is approximately only half that at 40 deg. F. and such a rise of temperature would double the flow of water. If the droplet of water which forms at the dripping point falls off due to its own weight before it is picked up by the wire loop of the pendulum, the impulse to the pendulum is lost and the clock will stop after a few seconds.

On the other hand an inadequate supply of water may be caused by a fall in the temperature of water or (particularly if untreated tap water is used) by the slow clogging up of the fine plastic tube from the "constant level" tank to the dripping point. If the weight of the droplet picked up by the wire loop is too light the amplitude of the swing of the pendulum is reduced to the point where the wire loop finally fails to touch the droplet and again the pendulum loses its impulse and the clock will stop.

The clogging up of the fine tube may be very largely reduced by the use of well-filtered water to which some copper sulphate has been added. Instructions for the periodic cleaning of the tube are given in Section IV. (An alternative method of counteracting clogging would be to use either a mechanically operated self-cleaning tube or valve but this has not been tried).

If the height of the constant-level tank is adjusted to the optimum position the clock will cope with temperature variations of approximately plus-or-minus 15 deg. F.

NOTE:- In a later model of the clock an automatic mechanism has been fitted to control the flow of water to the dripping point. Approximately every 15 minutes a "sensing finger" is brought into operation to test the amplitude of the swing of the pendulum. If the amplitude is beyond the desired point the flow of water is reduced by a small amount, and if less than the desired point the flow is increased. This automatic device compensates for all changes of temperaure and for the slow clogging of the tube until the limit of automatic adjustment has been reached. Cleaning of the tube must then be carried out.

This later model was not considered suitable for public exhibition because the relative complexity of the automatic mechanism detracts from the simplicity of the water-drop drive which is the essential feature of the clock.

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SECTION III - SOME TECHNICAL DETAILS

The clock runs best when the water flow is approximately one thousandth of an ounce per second, i.e. about 4.5 pints per day. But satisfactory running will be maintained provided the flow is not less than approximately 3.5 or greater than 5.5 pints per day.

The constant-level tank has only one moving part, viz. - the float itself. A small rubber disc affixed to the centre of the top of the float is pressed lightly into contact with the end of the water inlet tube and controls the required "leakage" into the tank. It is never required to completely stop the flow. The water level is maintained at a remarkable steady height - no change is perceptible by eye.

The "escapement" function of the clock is performed virtually without mechanical parts.

The pendulum axis rolls on its supports to keep friction to a minimum, and the three limit stops at each end of the axis ensure that the wire loop at the end of the extension is maintained in its correct position relative to the dripping point.

There are only three wheels in the clock and all are identical in size and have 60 teeth. Each wheel is made by hand from an aluminium disc by making 60 equally spaced radical cuts round the periphery and then twisting each tip through 90 degrees with a pair of pliers. To obtain uniform pitch for all teeth it is only necessary to bend the teeth slightly to the accuracy required. Because of the pawl drive however, no real precision in pitch is necessary and wear on the teeth is minimal.

There are several ways in which the power of the water-droplet drive could be increased if this were necessary for a larger and heavier clock:-

(i) By a modified type of wire loop the weight of the water droplet may be increased at least 4 or 5 times.

(ii) Instead of descending only 8 inches (as in the present design) a different design will permit of a vertical travel of even 3 ft. or 4 ft. while occupying less lateral width than the present design and without increasing the amplitude of the swing of the pendulum.

(iii) The frequency of picking up droplets may be increased.

(iv) Any number of droplets may be picked up simultaneously by having 2 or more wire loops on the pendulum arm picking up droplets from a corresponding number of dripping points.

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SECTION IV - INSTRUCTIONS FOR OPERATIONS & MAINTENANCE

A. To prepare for running

Lift the lid off the smaller ("constant level") tank and remove the main reservoir from its stand. Flush out the main tank. Clean the nipple at the end of the tube in the cover of the constant-level tank. See that water flows freely through the tube.

Pull the end of the fine plastic tube from the dripping point on the clock and remove the constant-level tank from its stand. Lift out the float. Clean out the tank being careful not to damage the end of the plastic tube. Extend the plastic tube in a straight line from the constant-level tank and carefully pass a straight length of wire right through the tube into the tank. Pull it back and forwards a few times and let it flush itself through by lowering the end of the tube. Repeat this operation to thoroughly clear the tube. Clean the float and its rubber disc.

Fill the constant-level tank about one-third full of water. Replace it on its support on the clock and insert the end of the plastic tube in the "dripping point" of the clock. The end of the tube should be inside the lower end of the dripping point - not projecting through it.

Place the float in the constant-level tank with the rubber disc uppermost. Place the main reservoir on its stand and very carefully place the cover on the constant-level tank. Partly fill the main reservoir with filtered and copper-sulphate treated water. As the constant-level tank fills up move the cover as necessary to ensure that the float is inside its guides projecting down from the cover. When the float comes in contact with the end of the inlet tube drops of water should fall from the dripping point at the approximate rate of 1 drop every 2 seconds. If necessary, adjust the height of the constant-level tank to give this rate. The clock is then ready to start. The pool should be completely filled with water.

B. To Start the Clock

Using only very light finger touch push the top of the pendulum to the left until the wire loop on the end of the extension arm is well above the dripping point. Quickly release the pendulum. The pendulum should settle into its normal swing in a few seconds. At the top of its swing the wire loop should be approximately 3/16 to 1/4 inch above the lowest point of the dripping point. At the bottom of its swing the loop should dip well into the pool. (See also "incorrect positioning of wire loop" under Section IV G below). Adjust the height of the constant-level tank till satisfactory running is obtained.

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C. To set the Hands to the Correct Time

DO NOT TOUCH THE CLOCK HANDS - they are only attached to their spindles by adhesive.

DO NOT TURN THE CLOCK ANTI-CLOCKWISE - the pawls permit of only clockwise rotation.

Firstly, by the lightest of finger-tip touch on the top teeth of the "second" wheel turn it until the second-hand is at the correct time. Then turn the "minute" wheel similarly, and finally the "hour" wheel.

D. Lubrication

It is suggested that the clock be lubricated every 6 months or so. This can be done without dismantling and even without stopping the clock. An easy way is to apply ordinary "household" type of oil using a 6 inch length of stiffish paper tapering to a point. Moisten the end of the taper with oil and apply it to the following points:-

Both ends of the pendulum axis where it rolls on its supports and where it may touch the three limit stops at each end.

The 4 bent-wire bearings which support the wheel spindles.

Both ends of the "second" wheel spindle where it passes into the "minute" wheel spindle.

Both ends of the "minute" wheel spindle where it passed into the "hour" wheel spindle.

The wire cam attached to the front of the "second" wheel and also the pin actuated by the cam.

The 5-start wire cam attached to the front of the "minute" wheel and also the pin actuated by it.

The axis pins of the 3 pawls which drive the second, minute and hour wheels.

A touch of oil on the tips of a few teeth on each wheel to lubricate the pawls as they slide down over the tips of the teeth.

NOTE: DO NOT LUBRICATE THE RETAINING PAWLS of the "second" and "minute" wheels since any stickiness of their guides may lead to their failure to function.

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E. Cleaning

The action of the clock is robust enough to have withstood running in a kitchen for 18 months with no cover whatever over the clock and the whole of the mechanism of the clock has been subject to deposits of dust, fluff, cooking fumes and even cobwebs. If the clock is protected by a cover, cleaning should not be necessary.

F. Adjustment of Clock Rate

The rate of the clock can be adjusted by moving the small square block of rubber up or down the vertical wire attached to the pendulum. The rubber is a very tight fit and adjustment is best carried out by first lifting the pendulum out of the clock. In so doing, care must be taken not to bend the pendulum extension arm and wire loop. When replacing the pendulum lift the pawl upwards out of the way until the pendulum is fully in position.

G. Causes of Mal-functioning

(a) Inadequate water supply

This is by far the commonest cause of stoppage of the clock. It is almost always due to a fall in temperature increasing the viscosity of the water and thus reducing the flow and/or clogging up of the fine plastic tube giving a reduced flow of water.

As the clock here described is not fitted with automatic control of the flow of water, the only method of guarding against a fall in temperature is to adjust the height of the constant-level tank as high as practicable. This of course also provides for the longest period of running before clogging up could occur.

Although, during the 18 months experience with the clock, there have been many failures due to inadequate water supply, these have been due to the deliberately adverse conditions. As explained earlier, the clock has been completely uncovered and thus exposed to dust and fluff etc. Also the clock has been positioned on the ledge of, and in actual contact with, a large window whereby the whole of the clock is frequently subject to hours of direct sunlight during the day and very cold conditions at night. Finally, it has been run on unfiltered water straight from the tap.

No records have been kept of temperature conditions and periods of running before failure has occurred but it is considered that when the clock is inside a large building and supplied with filtered and treated water there are unlikely to be failures of this sort provided a regular routine is established for cleaning the plastic tube. Depending on the degree of cleanliness of the water a fortnightly or monthly cleaning should be adequate.

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(a) Inadequate water supply (continued)

To clean the tube the constant-level tank may be left on its stand. Withdraw the end of the tube from the dripping point and extend it in a straight line from the tank. Pass a straight length of wire through the tube right into the tank and push it back and forwards a few times. Then lower the end of the tube to let it flush itself out. Repeat the process if necessary and replace the end of the tube in the dripping point as earlier described. Re-start the clock.

Note: It will be found necessary to adjust the height of the constant-level tank if there are marked changes in air temperature. Possibly three different heights would suffice for the year - a low height for summer, a high height for winter and an intermediate height for spring and autumn.

(b) Pawl failure

If, although the clock appears to be running correctly, it is unaccountably losing, a pawl failure should be suspected. If it is only an intermittent failure it may be hard to detect. There are two types of this failure:-
(i) Pawl-lever failure and (ii) Retaining pawl failure.

(i) Pawl Lever Failure

Each of the pawl levers between the two pairs of wheels has a pin at the right-hand end which is slowly pushed down by the cam as it rotates. When the pin comes to the end of its cam, the weight of the pawl on the left end of the lever should flick the pin up till it hits the lowest part of the cam, and at the same time of course the pawl should fall back to engage the next tooth on the wheel. If there is excessive stickiness of the axis pin the pawl-lever may fail to operate in this way and the minute-wheel may lose one-fifth of an hour.

(ii) Retaining Pawl Failure

These pawls (which engage the teeth of the "second" and "minute" wheels to prevent them from moving backwards as their pawls fall down) operate due to their own weight. Any stickiness of these pawls in their guides may prevent their coming into engagement. If a wheel does move backwards (though this will not necessarily happen when the retaining pawl fails) then once again either one second or one minute is lost.

To correct either type of pawl failure the axis pin and bearings of the pawl-lever or the guides of the retaining pawl should be cleaned. If desired to give more positive operation the weight of the pawl or lever may be slightly increased.

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(c) Incorrect positioning of Wire Loop

If the clock should fail to keep running although the water supply is known to be adequate first inspect the clock to see if there is anything impeding the rotation of the wheels and hands, e.g. hands touching the clock-face. Then try turning each wheel clockwise by very light finger touch on the top teeth. The "second" wheel in particular should be very free.

If this inspection reveals no defect closely examine the action of the wire loop in picking up droplets from the dripping point and releasing it in the pool. Any slight bending of the extension arm to the wire loop (which could occur during removal or replacement of the pendulum) will upset the positioning of the loop in relation to the dripping-point and may result in failure to cleanly pick up the whole droplet and deposit it in the pool.

The wire loop must not touch the tube of the dripping point. It must be a little clear of it since at the top of its upwards swing it rises 3/16 in. to 1/4 in. above the lowest point of the tube and for a moment the water droplet clings to both the loop and the dripping point. On the other hand the clearance must not be exessive.

At the top of its swing the loop should be as nearly as possible in line with the dripping point as seen from the side. If the loop is displaced too far to the back or front it may partially or completely dislodge the droplet without picking it up.

A simple test can be carried out to check whether the loop is in its correct position vertically. Start the clock and gradually lower the constant-level tank. As the water flow is thus descreased the swing of the pendulum will be reduced till finally either the loop will fail to pick up the droplet or alternatively it will fail to touch the pool. It is thought that the best adjustment of the loop is such that when it is only just picking up the droplet it is still quite clearly touching the pool.

If it is found necessary to reposition the wire loop it is only necessary to bend the wire to the loop till, by trial and error, satisfactory running is obtained.