Finding g using a water stream

Perhaps the first question we should ask ourselves is, 'Does the world need another experiment to find *g*, the acceleration due to gravity?' This activity is aimed at Advanced Higher, where investigations are not really about finding a physical constant. They generally involve evaluating methods. We feel that this technique is sufficiently interesting and different to earn its place.

Looking at the water stream in Figure 1, we see that the stream narrows as the water falls. Why is this?

Note that in the following discussion, we will use non-standard units of cm^3 and $cm\ s^{-1}$ for convenience. Please don't be upset.

Imagine water emerging from a tap at a rate of $X\ cm^3\ s^{-1}$

Suppose the water has a velocity of $u\ cm\ s^{-1}$

Suppose the stream has a radius of r_1 at this point

The cross sectional area A_1 of the stream is therefore πr_1^2

It follows that the volume of water per second $X = A_1 u$.

Rearranging: $u = X/A_1$

As the water streams downwards, it will speed up as it accelerates due to the force of gravity. The volume per second X will not change – if $X\ cm^3$ leaves the tap per second, $X\ cm^3$ enters the sink every second.

Suppose that at some point, the velocity of the water has increased to v.

$v = X/A_2$ where A_2 is the cross sectional area of the stream at this point.

Since v is greater than u and X has not changed, A_2 must be smaller than A_1. The stream narrows as the water travels downwards.

X can be measured by finding the time to collect a particular volume of water.

A_1 and A_2 can be found by finding the diameters of the stream at two points, then halving them to get r_1 and r_2 and using the formula for the area of a circle, $A = \pi r^2$.

u and v can then be calculated from X and A as shown above.

The vertical separation s between the two measuring points will need to be measured too.

Using the equation $v^2 = u^2 + 2as$, the acceleration a due to gravity can be found.

Making measurements

We have seen advice stating that a travelling microscope should be used to find the diameter of the stream. We have an alternative method which involves photographing the stream with a ruler alongside it. The ruler must be in the same plane as the stream.

The photograph can then be projected and measurements made. These measurements are then scaled, the scale being determined by the ruler.

Figure 1 – Water stream and ruler.

We suggest measuring the diameter of the stream at several displacements s from an arbitrary origin. Find the corresponding values of v at each point then plot a graph of v^2 versus s. This graph should be a straight line of gradient $2a$ where a is the acceleration due to gravity. See Figure 2. Note that we have not put error bars on the graph and have used large markers which, though unsuitably blobby for an Advanced Higher assignment, have been chosen for clarity for those reading this on a mobile device.

We have also used the free Tracker analysis package, most recently revisited in bulletin 272 [1] to measure diameter. Please get in touch if you would like more information on using this particular technique.

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We prefer the graphical method rather than choosing two points on the water stream. The above theory relies on the water flowing in a non-turbulent laminar manner. If the flow becomes turbulent for larger values of *s*, this manifests itself as the graph becoming non-linear. <<

References
[1] https://www.sserc.org.uk/publications/bulletins/272-spring-2021/

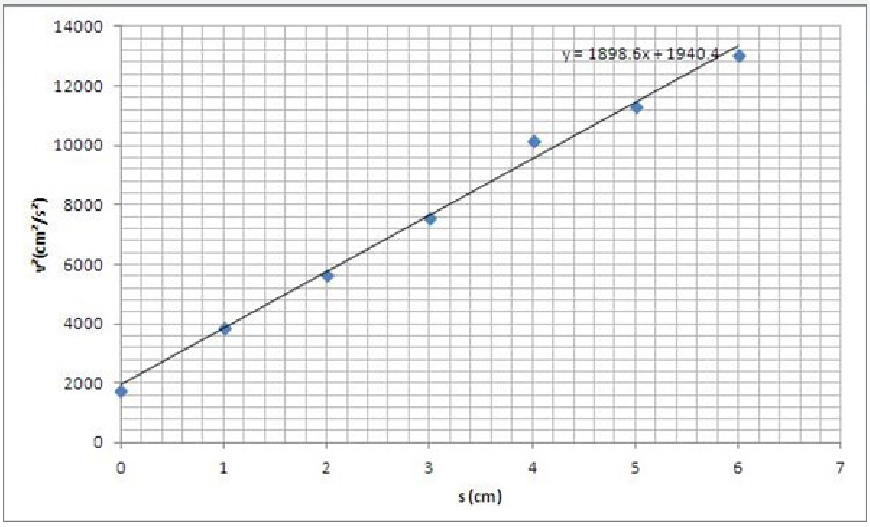

Figure 2 – graph of v^2 versus *s*.

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