Using an Abney Level to Measure Relative Heights

1) Introduction

An Abney level is a small surveying instrument that consists of a sighting tube and a spirit level linked to a protractor and this allows angles and slopes to be measured. It is named after its inventor, Sir William Abney (1843-1920) who was a British Chemist and Physicist and is known for his contribution to photography and Infra red spectroscopy. Probably the most common current use of an Abney level is in forestry for the height measurement of trees, but it is still used as a convenient “miniature theodolite” in topological surveys.

A typical Abney level, available from York Survey, is shown in the photograph below. The black square cross-section 2cm by 2cm sighting tube measures about 18cm long. The protractor attached to the side of the sighting tube measures 10cm by 7cm. Overall the instrument is lightweight at 120gms and is best carried within the supplied box to avoid damage. This box can either be attached to one’s belt or perhaps better, carried in one’s rucksack.

Note that the longer the sighting tube then the greater the potential resolution of the instrument, and Abney levels are available with sighting tubes of different lengths. For example York Survey offers a model with a 13.3cm tube. The tests described in this report were carried out on the model with the 18cm length tube. Shorter sighting tubes will be less accurate.

The sighting tube on this particular model of Abney level does not have any magnification which is a limitation in the observation of objects. Since there is no magnification, a focussing mechanism is not required and the length of the sighting tube is therefore fixed. However the author’s experience with an Abney level with 5 times magnification was unsatisfactory. Although ease in sighting the object and observation of the spirit level bubble were greatly improved, the focussing mechanism of concentric slide-tubes was sloppy. The side to side play in the construction gave inconsistent results when trying to differentiate similar heights and nullified the advantage of the magnification.

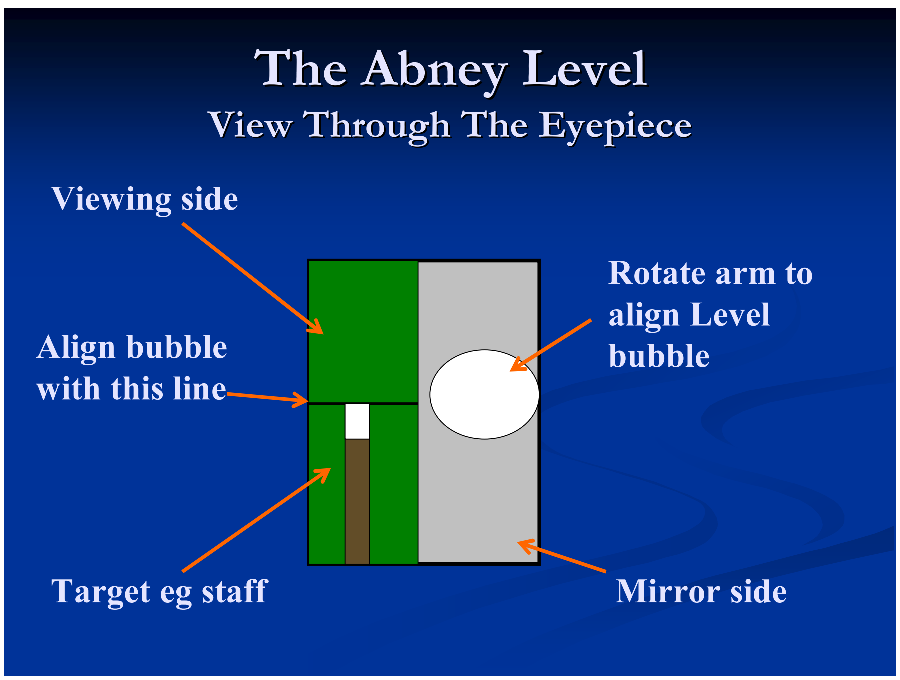
2) Main Features in the Use of an Abney Level

There are two main ways to use an Abney level:-

a) As a simple level to determine the horizontal and
b) As an Abney level to measure angles of slope or inclination.

The second method is clearly the main reason for using an Abney otherwise the protractor is redundant and a simpler "hand held" surveyors' level could be used. However, with the protractor set at zero then the Abney level effectively becomes a simple surveyors' level.

The view through the eyepiece of an Abney level is shown in the diagram below. The view is split in a vertical plane. In this case, on the left side is the view down the sighting tube to the object or target being "measured". When taking a measurement, this target is aligned with the horizontal line that runs left to right across the centre of the objective glass at the end of the sighting tube. Once that has been done the protractor is rotated to align the bubble, seen on the right hand side of the view down the sighting tube, with the horizontal line. The angle shown on the protractor therefore is the angle of slope from the Abney level to the target. If a height difference is required between Abney level and target, then of course a horizontal or slope distance needs to be measured independently, e.g. with a tape, GPS, Electronic Distance Measurer (EDM), etc. so that the height difference can be calculated from simple trigonometry.



If the protractor is locked off at zero, then the Abney level can be used as a simple level. The Abney level is pointed at the target and the bubble observed. If the horizontal line cuts ABOVE the centre of the bubble then the target is LOWER and vice versa. Alternatively one can set the Abney level to horizontal, that is, the bubble aligned with the horizontal line, and the position of the target observed relative to the horizontal line. If the target is ABOVE this line then it is HIGHER and again vice versa. Either method can be used but the latter feels more logical and is easier to remember. In order to improve the accuracy of measurements it is best to have the Abney level supported in some way. The support can be from natural objects e.g. a summit rock etc. or artificial supports e.g. tripod, monopod or trekking poles as described in the next section.

3) Measuring Relative Topographical Heights

A key issue for many hill walkers is the location of the summit position of a hill. In the majority of cases this is not an issue as visually it is clear but there are a significant number of occasions when the position of the summit is not obvious and then some kind of measurement is needed. Another option for hill baggers is to visit all the possible contenders so that one can be sure that the hill has been bagged. However, with the common use of hand held GPS instruments capable of identifying positions to within about 5m and these summit locations being available in Databases, the requirement to identify correct summit positions has become much more important.

The most accurate method to locate a summit position is to use an automatic level set up on a tripod and readings are taken from systematic staff placements until the highest point is obtained. However this technique falls into the realm of serious surveying and a hill walker is not going to carry this sort of equipment routinely. The hill walker requires something lightweight, accurate and if possible uses equipment that will normally be carried on the hills. The majority of hill summits that require an instrumental method to locate them can be found using an Abney level and two trekking poles.

Let us assume that we want to determine which of two points, A or B, is the higher. The most accurate way to do this with an Abney level and two trekking poles is to first set the two poles to the same length. Place one of the poles at point A and the other at an observation point half way between points A and B. With the Abney level supported on the top of the observation trekking pole a measurement of angle is made to the top of the pole at A.

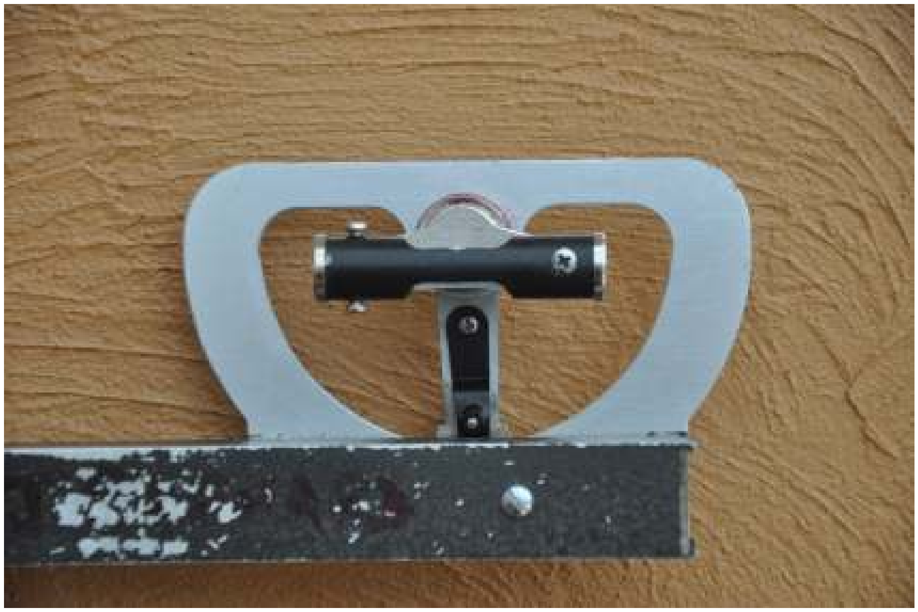
Without moving the observation pole, the other pole is moved to Point B. Observation through the Abney level will then determine which is the higher point. This method has two important advantages. Firstly by choosing to observe from the midpoint of A and B, the distance from the Abney level to each point is equal. If there were any inherent misalignment of the spirit level to the horizontal within the Abney, then this effect would be cancelled out in the observations. Secondly this method minimises the distance from Abney level to target thereby making it easier to take make accurate observations. However there are also downsides to this method. The vernier scale on the protractor allows readings to be taken to 0.2degrees but it is very difficult and fiddly in the field to set an observation angle to this level of precision. Also the terrain itself may not allow observations to be made from a mid point. This is true if one is trying to compare the heights of two rounded summits from a col between them when it may not be possible to see one or both of the target trekking poles.

In practice it is more common to place equal length trekking poles at A and B and observe A to B and then B to A. Using this method the protractor can be locked at zero and the Abney level is simply used qualitatively to show which point is the higher. It is very important to check that the Abney level is zeroed properly before measurements are taken and that the zero position is not changed during observations. Also it is important that the A to B and B to A readings point to the same conclusion. It is possible to make semi-quantitative measurements knowing the dimensions of the parts of the trekking poles. For example one might observe that point A is approximately three trekking pole handles higher than point B and for the author's trekking poles that would mean a height difference of about 0.4m.

Using the above method, at times one may not be able to draw the same conclusion from an observation and its reverse. There are a number of reasons for this. A lot will depend on the operator. Factors like one's eyesight and the ability to hold the Abney level steady to take measurements, particularly for targets at longer distances and near the limit of instrument resolution, are fundamental. Weather conditions are a significant factor and in poor light/light mist/rain it can be very difficult to even see the target! Another reason why observations are made to the tops of trekking poles, apart from getting above any vegetation that would confuse measurements, is to have a background of light sky which makes observation of the trekking pole much easier. If the background behind a trekking pole is dark, e.g. a hedge, a hillside or a wall etc. then it can be almost impossible to resolve the target. However, there may be a problem with the instrument itself and eliminating this is the subject of the next section.

4) **Adjusting the Abney level – Eliminating Collimation Error**

As with all measurement instruments it is mandatory that the operator takes all steps to ensure that the instrument is functioning properly for measurements to mean anything. Even when an instrument is brand new or taken out of the box for the first time if second hand, the question "Does this instrument measure correctly?" should be addressed, answered and rectified if not. Assuming there is no obvious damage, as with all optical levels, one needs to ascertain if the optical train is aligned to the spirit level. For example when the spirit level tells you the instrument is horizontal then it may in fact be pointing up or down and that clearly will cause inaccuracies in any readings taken. This is called a collimation error. If any adjustment to realign the Abney level to the spirit level is needed, then this should be done using the small screws at the rear end of the spirit (left end) – shown in the photograph below.



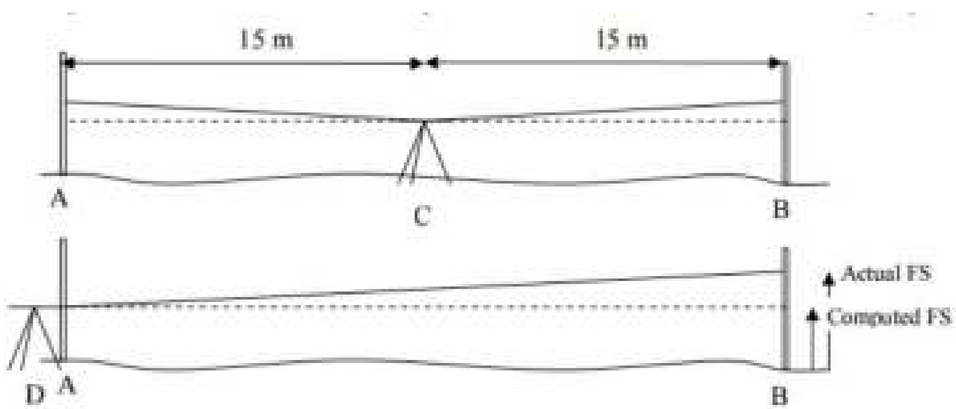
If the rear end of the spirit level needs to be adjusted downwards then the bottom screw should be loosened first before tightening the top screw in a staged process and of course vice versa. Several attempts may be needed to get this right. For those who fear tampering with adjustment screws because of the risk of making things worse and not being able to correct them, the adjustment can be made in a simpler way. The protractor can be loosened from its zero position and tightened at the angle setting that gives horizontal readings. This correction should be very small and needs to be remembered if the Abney level is used to make angle measurements.

5) Aligning the Abney Level to the Spirit Level

Probably the simplest method to achieve alignment is to use the fact that water surfaces are level. Set two poles of equal length at either side of a lake/pond/etc. and with the Abney protractor set to zero, observe the top of one pole from the Abney level resting on the top of the other. If one sees exactly the top of the other pole aligned with the horizontal line then the Abney level is adjusted properly, although it is a good idea to repeat the measurement in the reverse direction to confirm the calibration. If the distance from pole to pole is quite short then the 1cm correction for the thickness of the Abney level barrel should be taken into account. Ideally the poles should be at least 10m apart. If this is tried with the poles at large distances then the benefit of the larger distance has to be set aside to one's ability to be able to make clear observations which are more difficult at greater distances.

The recognised method for eliminating collimation error in any optical level is called "The Two Peg Test" and is shown diagrammatically below. Two surveyors' staffs are held vertically at points A and B, normally about 30m apart; the ground does not have to be level. The optical instrument, supported on a tripod and set up so that it is level, is positioned at point C midway between A and B. The dotted line (upper diagram) represents the true horizontal and would be the actual staff readings at A and B. However if there were collimation error in the level, in this case the level was pointing upwards when it had been set up at C, then the staff readings A and B would be those for the solid line. Since the height error caused by the collimation error is the same at both staffs, the difference between readings A and B will be a true height difference since the error in each reading cancels out.

The level is then moved to position D, adjacent to staff A, and readings are taken from the two staffs (FS = Foresight as opposed to BS = Backsight in the opposite direction). From the lower diagram it can be seen that the difference in the two staff readings will now include the contribution from the collimation error. However the "true" reading for B can be calculated from the difference in A and B readings when the level was placed at mid point C and therefore the level can be adjusted to that reading to complete the accurate calibration. In practice the procedure is repeated until consistent results are obtained.



Now the problem with this method is that the average Abney level user may not have access to two surveyors' staffs and a tripod. Also it would be very difficult (impossible?) to make an accurate staff reading with an Abney level at a distance of 30m. So is there a simpler method that incorporates the principles of the "Two Peg Test"? The answer is "Yes" and an assistant is needed to do it.

First identify two vertical surfaces (A and B) e.g. walls, trees, fences anything will do, approximately 10-15m apart. With a tape preferably but paces would be OK, find the mid point. First check that the protractor on the Abney level is set and locked off at zero. Support the Abney level on a trekking pole (if it can be clamped in a tripod of some sort even better – e.g. a camera tripod and a small G Clamp will work) above the mid point between A and B and hold it horizontally on the spirit level while looking at vertical A. The assistant then needs to place a mark (a scratch, some thin tape, a marker pen etc) on A at the point that is being observed. Then turn through 180 degrees and carry out the same procedure for vertical B, but it is essential not to adjust the height of the trekking pole for this! Now move close to point A and observe the mark there through the Abney level. Now the height of the trekking pole will need to be adjusted so that this point can be brought into view. Once that has been achieved, the mark on vertical B is observed. If that is seen on the horizontal line then the Abney level is correctly adjusted. However if the observation is below or above the mark at B, then the adjustments as described in Section 4 need to be carried out. Of course the process needs to be repeated until consistent results are obtained.

6) How good are Abney Level Measurements?

Answering the question "How good are Abney level measurements?" is difficult because so much depends on the operator and the conditions that he is working under. However, a better question is to add the rider "under ideal conditions". By answering this we will have a view of the capability of the instrument and will know when we are going beyond its bounds. It is interesting to read entries in the Database of British and Irish Hills where different operators have drawn different conclusions but basically all using the same type of instrument! So this could be a result of operator error, differences in operator ability, differences in individual Abney levels, incorrect calibrations and finally trying to use these instruments beyond their capability or resolution.

Therefore we decided to carry out some experiments to try to quantify the resolution of our Abney levels. These were carried out on one of our local football pitches where the ground is, or should be, level. Two trekking poles were placed vertically in the ground at a distance of 25m apart as measured with a steel tape. A Leica NA730 automatic level set up on a tripod was placed at the mid point. Each trekking pole was then adjusted in height so that they were both level. The setup is shown in the next two photographs; perpendicular and parallel to the trekking poles respectively.

Two Abney levels were used in these tests and each operator carried out the test with both Abney levels. Each trekking pole was observed from the other with the Abney level supported on the top of the pole. (Earlier this day the calibrations of the two Abney levels had been checked with a variation of the “Two Peg Test” which was described in Section 5). Neither operator with either Abney level could discern any height difference between the two trekking poles when viewed from both directions.

Next one of the trekking poles was raised by 0.10m. This means that the slope over 25m from the top of one pole to the other was now 0.2degrees, equivalent to 2 divisions on the vernier scale. Both operators with each Abney level could discern the height difference correctly and estimate it to be about the size of a trekking pole handle (0.13m).

The height difference between the trekking poles was then reduced to 0.05m which then gives an angle of slope of 0.1 degrees equivalent to one division on the vernier. In this case only one of the Abney levels was able to resolve the height difference and therefore we considered this to be the limit for resolution. To remove the difficulty of holding an Abney level very steady to make measurements, one was mounted on a horizontal tribrach which in turn was supported on a rackable tripod. This setup is shown in the next two photographs.

With the tripod positioned next to the lower trekking pole, the tripod was adjusted with the height racking lever until the top of the pole coincided with the horizontal line on the Abney. Then the other pole was observed. This was repeated with the other Abney and the same conclusion found that one of the instruments could resolve but the other could not. There was no doubt too that an Abney level held steady and horizontally by this method made taking readings easier but not enough to counteract the differences between the two Abney levels.

The observations were then repeated with the trekking poles set 50m apart and 0.20m different in height giving a slope angle of 0.2 degrees. The dark backgrounds (hedges) behind the trekking pole being observed made seeing the top of the pole much more difficult at this longer distance. To get observations one of the operators had to grip the handle of the trekking pole being observed as “white skin” made the top of the pole much easier to see. The overall conclusion was the same as before that one Abney level was able to resolve but the other not. (In practice on the hills where high points are being compared, the background is likely to be sky and therefore lighter which would make seeing the top of the trekking poles much easier.)

No value was seen in carrying out further observations with the trekking poles set apart at even greater distances.

7) Other Instrument limitations

We have measured the horizontal line “etched” onto the objective glass of the Abney level to be about 0.25mm wide. As the sighting tube is about 170mm long this means that the horizontal line subtends an angle of 0.084 degrees. Therefore within that angle it will not be possible to view the target. At distances of 10m, 20m 50m and 100m the height of target not visible is 1cm, 3cm, 7cm and 15cm respectively. So essentially on this fact alone you cannot resolve a height difference of 15cm at 100m!

8) Summary and Conclusions

The Abney level is a useful lightweight instrument to carry in case relative heights need to be compared, in particular to locate the summit of hills.

For most uses a handheld surveyors’ level would be adequate but would not have the angle measurement facility of the Abney level.

The Abney level needs to be calibrated regularly to make sure that the spirit level and sighting tube are correctly aligned.

Before taking any reading one should always check that the protractor is clamped to zero (or any other number that equates to calibration for the specific instrument). The author finds it easy to move the protractor off the calibration setting if the Abney level is forced the wrong way around into its carrying box!

To achieve the most reliable observations towards the limit of resolution the Abney level needs to be supported in some way.

Abney levels seem to vary slightly in performance from unit to unit even with the same model. The critical factor for the two Abney levels used in this study was the shape of the spirit level bubble. One was more spherical than the other and this made it easier to align to the horizontal line.

The study here indicates that the resolution of the Abney level is about 0.2 degrees and the height resolution at various distances for this angle is shown in the table below. These resolutions assume ideal conditions and in practice should be considered as best values.

Distance to Observed Object m	**Resolution cm**
10	3.5
20	7
50	17
100	35
200	70

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