1998BASI...26..119R

Bull. Astr. Soc. India (1998) **26**, 119-125

An improved gnomon

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Abstract. During a project work done by a group of students at senior secondary stage with the guidance of the author, the vertical pillar kind of gnomon has been improved upon. Whereas the traditional gnomon can measure altitude of the Sun with a precision of about 0.25 degree, the improved one can measure it with a precision of about 0.05 degree, by the observation of its shadow only. It also enables in toto to make the plane surface on which it is placed accurately horizontal.

Key words : astronomy education, gnomon, experimental physics

1. The traditional gnomon

The traditional gnomon is a shadow instrument with its shadow by sunlight on an appropriate surface for studies related to Sun. It may take several shapes :

(1) A vertical pillar casting its shadow on a horizontal plane surface.

(2) A straight edge parallel to axis of earth casting its shadow on a horizontal or vertical plane surface.

(3) A straight thin rod parallel to axis of earth casting its shadow on a plane perpendicular to it or on a cylindrical surface co-axial with it. The gnomon of type (1) above, being the simplest, is quite popular for several kinds of activities at school level, for example :

(a) Study of the length of the shadow with the position of Sun going up in the sky (for primary classes). Altitude of Sun can be found at a particular date and time (for secondary classes), as shown in Fig.1. If p is the height of the gnomon and b the length of the shadow, then the altitude of sun $d = \tan^{-1}(p/b)$.

(b) Finding the true north direction, which is the bisector of equal shadows in forenoon and afternoon, preferably on solstice days.

(c) Measuring the local time (Fig.2) with gnomon shadow GT from a few hours before noon to

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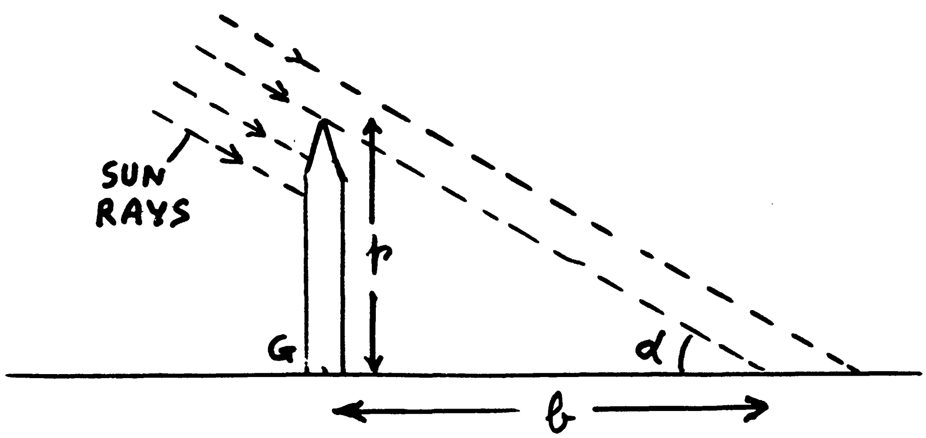
a few hours afternoon time. Here OG = cot p, and the angles θ made with line ON by OT at various hour angles H are given by $\Theta = \tan^{-1}(\sin\phi \tan H)$. Here T is the tip of gnomon shadow.

(d) Finding the altitude of Sun at noon and studying variation in it on different dates. If latitude ϕ is known, then declination δ of Sun at noon on that date can be found out. If declination δ of Sun is known from the ephemeris (or is 0, or 23.5, or -23°.5 on that date) then latitude ϕ can be found out (Fig.3). Here $\phi - \delta = 90 - \alpha$.

(e) Finding altitude of Sun at noon on same date simultaneously at two places which are at least 300 km apart in North-South direction, thus finding radius of the earth (Fig.4). If α_1 and α_2 are meridian altitudes of the sun at stations A and B respectively, then $r = d \times 57.3/(\alpha_2 - \alpha_1)$, where d is the distance between A and B.



Figurel. Shadow of a gnomon at Sun's altitude α.

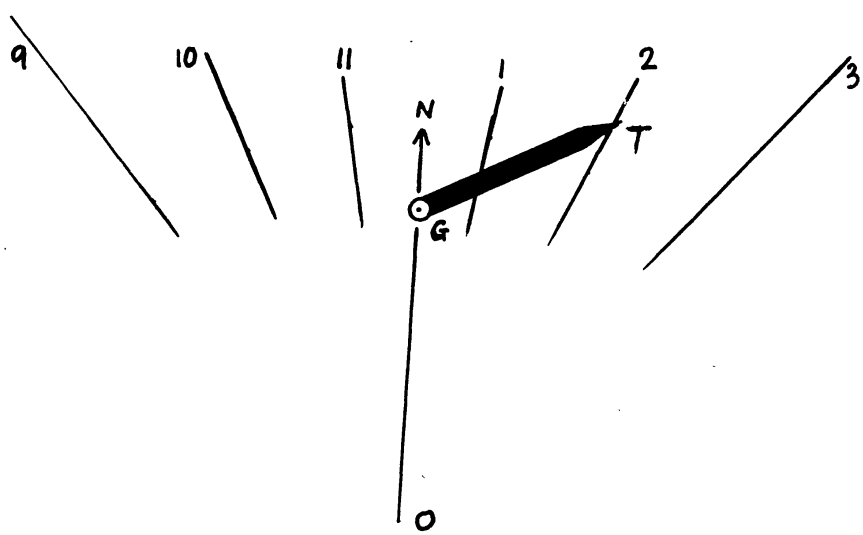


Figure 2. Measurement of local time with the tip T of gnomon shadow.

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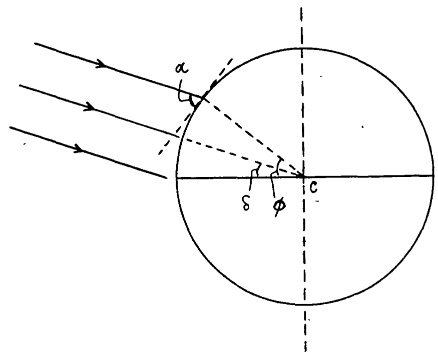

Figure 3. Sectional diagram of the earth in relation to the direction of the Sun.

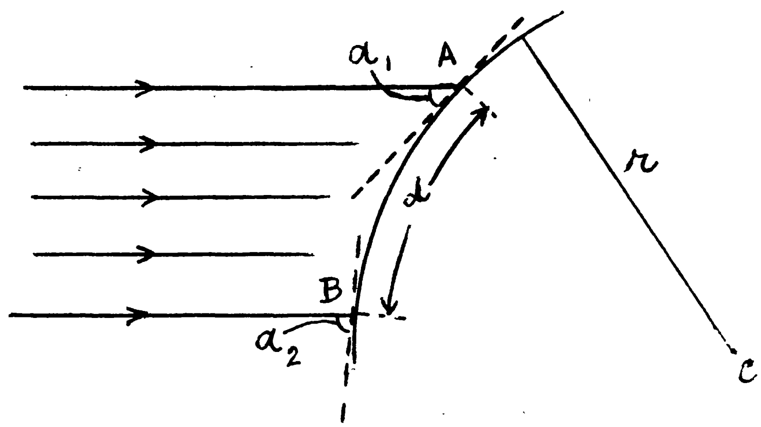

Figure 4. Measuring the radius of the earth.

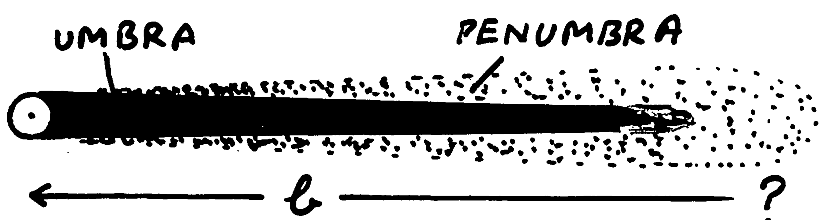

Figure 5. Confused shadow of a gnomon

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2. The need of precision in the project

In October 1993, a group of students from a school in Delhi was working on their project with the author. They wanted to find the radius of the earth by gnomon. But their difficulty was that collaboration 300 kms away could not be sought, though simultaneous measurement at two places 50 km apart within Delhi was considered possible.

In traditional use of gnomon we measure length of the shadow assuming Sun to be a point source of light, casting a shadow with sharp boundaries. But, in reality the shadow does not have sharp boundaries. It has a dark umbra and a penumbra with various shades of light (Fig.5). Thus the length of shadow cannot be accurately measured. As the Sun has an angular diameter of 0.5 degree, the measured altitude has an error of about 0.25 degree.

3. The innovation to achieve precision

One of the students pointed out that we are interested in the shadow of the tip of the gnomon. A sharp pointed end casts a blurred penumbra. But if with a spherical source of light like the Sun, we have a spherical object casting the shadow, center of that shadow can be found by judgement much more precisely. So a small ball was placed at the top of the gnomon. The ball is of such a diameter that its umbra is quite small and thus centre of elliptical shadow on the horizontal plane can be judged easily and accurately. In (Fig. 6) A is the centre of the tiny ball at the upper end of the gnomon made vertical by the plumbline AB and C is the centre of the elliptical shadow of the ball.

4. Construction of the improved gnomon

A tripod with a glass base was constructed. The glass plate was chosen to be a plane of good quality by observing the reflected image of a distant object in it. At the top of the tripod a vertical sewing needle was fixed with its pointed end upwards. On this pointed end a small ball made of dough (which is used for making chapaties) was fixed (Fig.7).

From the eye of the needle a plumb line was suspended. A graph paper was pasted on the base plate of the glass. Care was taken to use both ends of the thread passing through the eye of the needle for suspending the plumb line. The symmetry thus obtained in the shape of hanging thread makes the plumb line precisely vertical, in spite of some stiffness of the thread. The bob of the plumb line was also improvised by tying three equal rods on a sewing needle 7.5 cm long, with 1 cm of pointed end of this needle coming out of the rods to function as a pointer to read the position of the plumb line on the graph paper. Position of the tip of the plumb line, T, when this gnomon stands on an accurately horizontal plane is found as follows.

The gnomon is first placed on a plane glass surface, which may not be horizontal. Then coordinates of the position, T_1, of the tip of the plumb line are read on the graph paper (Fig.8a).

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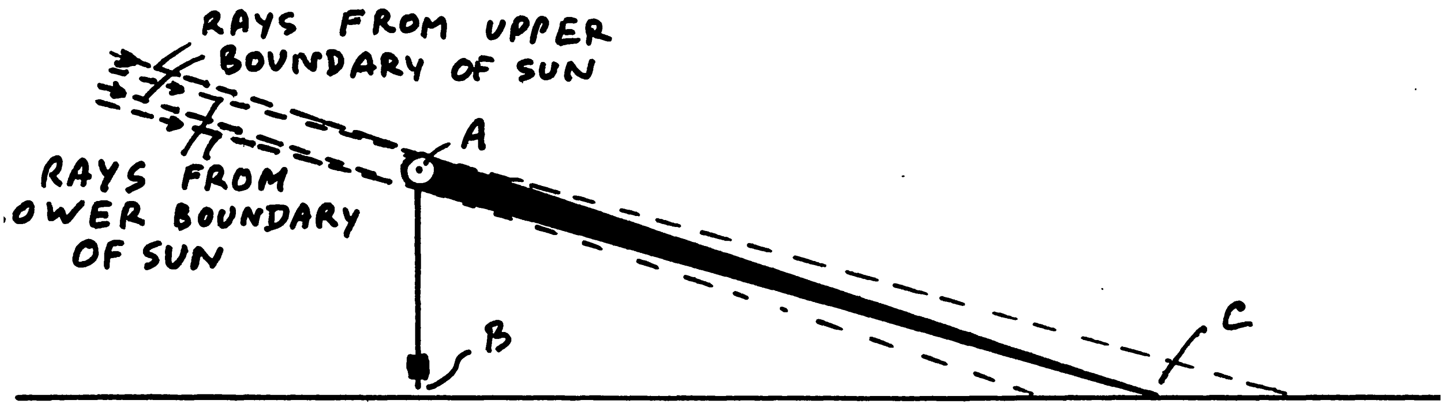

Figure 6. Shadow of a ball-tipped gnomon

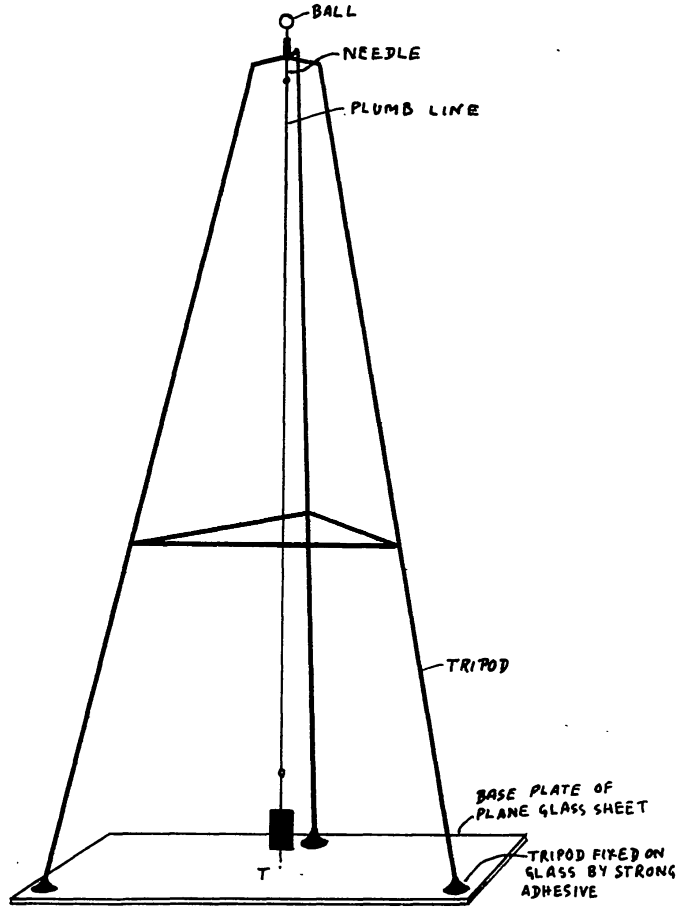

Figure 7. Construction of an improved gnomon

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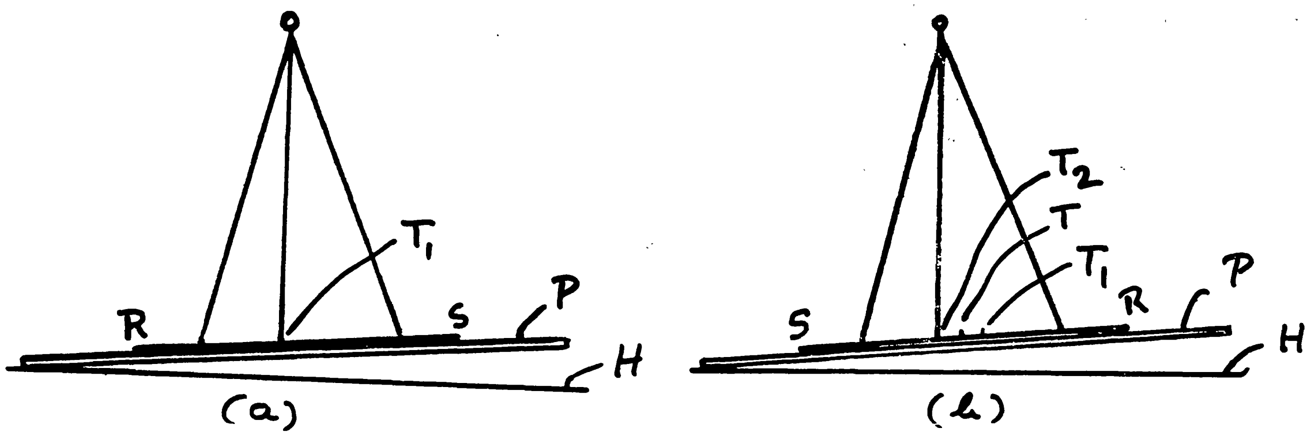

Figure 8. Finding the tip of the plumb line for an accurately horizontal plane.

Next, the gnomon is rotated through 180 degree and coordinates of the new position, T_2, of the tip of the plumb line are read. Mid-point of the line segment joining T_1 and T_2 is the position of the tip of the plumb line for an accurately horizontal plane. Now, the glass sheet on which the gnomon stands can be adjusted, to bring the tip of the plumb line at T, thus making it accurately horizontal.

The students then took up the more comfortable project to find the declination of Sun each day for two weeks by measuring meridian altitude of sun at one place only. Accurate latitude of that place was found from a map of Survey of India. Two slightly cloudy days being lost, results for 12 days were obtained. On comparison with data given in Indian Ephemeris, large systematic deviation was observed. However, when declination of sun for the noon time at Delhi on each day was interpolated, from the data given in Ephemeris, the agreement was good. Mean error of results was 0.05 degree (that is, 3 arc minutes), though on some days, the error was upto 0.12 degree.

5. A message of national importance

The author wants to communicate a message through this example of innovation by school students. Whereas our children should share the pride for Heritage of Ancient Indian Astronomy, we must not stop there. We must, at the same time promote their creativity. Practical work and project work in science, which should promote one's creative ability and is a part of curriculum, needs to be taken up honestly in schools and colleges. The most creative age in the development of a person is from 15 years to 35 years. There was a time when individual research work could fetch one a Nobel prize and each year this prize in physics was won by a young person below 35 years of age. Even the big projects which fetch a Noble prize to elderly people now-a-days, cannot succeed if we do not promote creativity of the young science students in schools and colleges. In the Indian context, unless we genuinely promote creativity of young science students in their formative years, we are not going to be able to face international competition which is now inevitable in the new economic environment.

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Acknowledgements

Thanks are due to Gaurav Bansal, Bharat Bhushan, Nitin Jain and Sandeep Juneja, the students of C.R.P.F. Public School, Sector 14, Rohini, Delhi 110 042, during the session 1993-94, for their sincere and intelligent project work, which lead to the development of the improved gnomon.

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