NASA TECHNICAL
MEMORANDUM

Report No. 53931

44

COMPARISON OF EXPERIMENTAL AND THEORETICAL BRIGHTNESS TEMPERATURES OF THE LUNAR SURFACE FOR DIFFERENT ELEVATION ANGLES OF SUN AND OBSERVER

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September 16, 1969

NASA

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R-SSL-INT-67-11 October 6, 1967
This Internal Note was changed to NASA TM X-53931 on September 16, 1969

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I. INTRODUCTION

A semi-empirical mathematical expression has been developed by Ashby [1] for predicting the surface infrared radiation from a local area of the moon as a function of sun position and angle of observation. The brightness temperatures calculated by using this expression are compared with the experimental data given in References 2 and 3.

II. MATHEMATICAL EXPRESSION

The expression developed by Ashby [1] is:

$$B(i, \epsilon, \alpha) = \frac{a_1 \cos i + a_2 \cos \alpha'}{1 + a_4 \dfrac{\sin \alpha'}{\cos i}} + \frac{a_3}{\pi}\left[(\pi - |\alpha|)\cos|\alpha| + \sin|\alpha|\right], \qquad (1)$$

where $B(i, \epsilon, \alpha,)$ = infrared radiance in cal/min - cm^2 - steradian;

a_1 = 0.481 cal/min - cm^2 - steradian

a_2 = 0.140 "

a_3 = 0.074 "

a_4 = 0.121 "

(The values of a_1 - a_4 were determined from the experimental data in Reference 2.)

$$a' = \frac{\pi}{2}\left(\frac{i^2 + \epsilon^2 - 2 i \epsilon \cos(\phi_i - \phi_\epsilon)}{\dfrac{\pi^2}{4} + \dfrac{4 i^2 \epsilon^2}{\pi^2} - 2 i \epsilon \cos(\phi_i - \phi_\epsilon)}\right)^{\frac{1}{2}}$$

$i, \epsilon, \alpha, \phi_i, \phi_\epsilon$ = angles defined in Figure 1.

From Equation (1), the infrared energy is defined as:

$$I(i, \epsilon, \alpha) = B(i, \epsilon, \alpha) \cos \epsilon , \tag{2}$$

and the brightness temperature as:

$$T = \left[\frac{\pi B(i, \epsilon, \alpha)}{\sigma} \right]^{\frac{1}{4}} , \tag{3}$$

where σ = Stefan-Boltzmann constant

$(0.826 \times 10^{-10}$ cal/min - cm^2 - $°K^4$).

III. RESULTS

The results obtained from calculations using Equation (3) are compared with the experimental results (10 to 12μ band) of Saari and Shorthill in Figures 2 - 11. In Figures 2 - 5, 10, and 11, the temperatures are observed in a plane defined by the normal to the lunar surface and an observer vector at $\phi_\epsilon = 0$ (see Fig. 1). The sun vector is also in this plane, i.e., $\phi_i = 0$. In Figures 6 - 8, the temperatures are observed in a plane defined by the normal to the lunar surface and an observer vector at $\phi_\epsilon = 45°$. Figure 9 shows the temperatures as observed in a plane defined by the surface normal and an observer vector at $\phi_\epsilon = 90°$. The parameter is the sun position measured from the surface normal in Figures 2 - 9, but from the surface in Figure 10. The experimental data in Figures 2 - 9 have not been corrected for albedo effects, as they have been for the experimental data in Figures 10 and 11. The experimental results in Figure 10 are actually a least square polynomial fit to the data.

Notice on Figures 5 - 8 that the experimental data are given for both a morning sun (just after sunrise) and an evening sun (just before sunset), while on Figures 2 - 4 and 9 the experimental data are for only a morning sun.

Figure 11 presents the theoretical and experimental values of the limb brightness temperature at the thermal equator. The observer position is fixed while the sun position changes.

All the temperature values shown in Figures 2 - 11 are observed (or calculated) in three separate planes. Calculated values for all planes are given in Figure 12, in which a three-dimensional plot of Equation (3) for two sun angles is shown. Notice that the directionality decreases as the sun approaches the straight-overhead position, where the directionality will disappear altogether in reference to the azimuthal plane and will approximate the Pettit and Nicholson measurements in the elevation plane.

REFERENCES

1. Ashby, Neil: Study of Radiative Aspects of Lunar Materials. P. E. C. Research Associates, Inc., Final Report on Contract NAS8-20385 covering period April 26, 1966 to January 26, 1967.
2. Montgomery, C. G.; Saari, J. M.; Shorthill, R. W.; Six, Jr., N. F.: Directional Characteristics of Lunar Thermal Emission. Brown Engineering Company, Inc., Tech. Note R-213, Nov. 1966 (also published as Boeing Document D1-82-0568, November 1966).
3. Saari, J. M.; and Shorthill, R. W.: Review of Lunar Infrared Observations. Boeing Document D1-82-0586, December 1966.
4. Sinton, W. M.: Temperatures on the Lunar Surface. Chapter 11, Z. Kopal, Physics and Astronomy of the Moon. Academic Press, 1962.

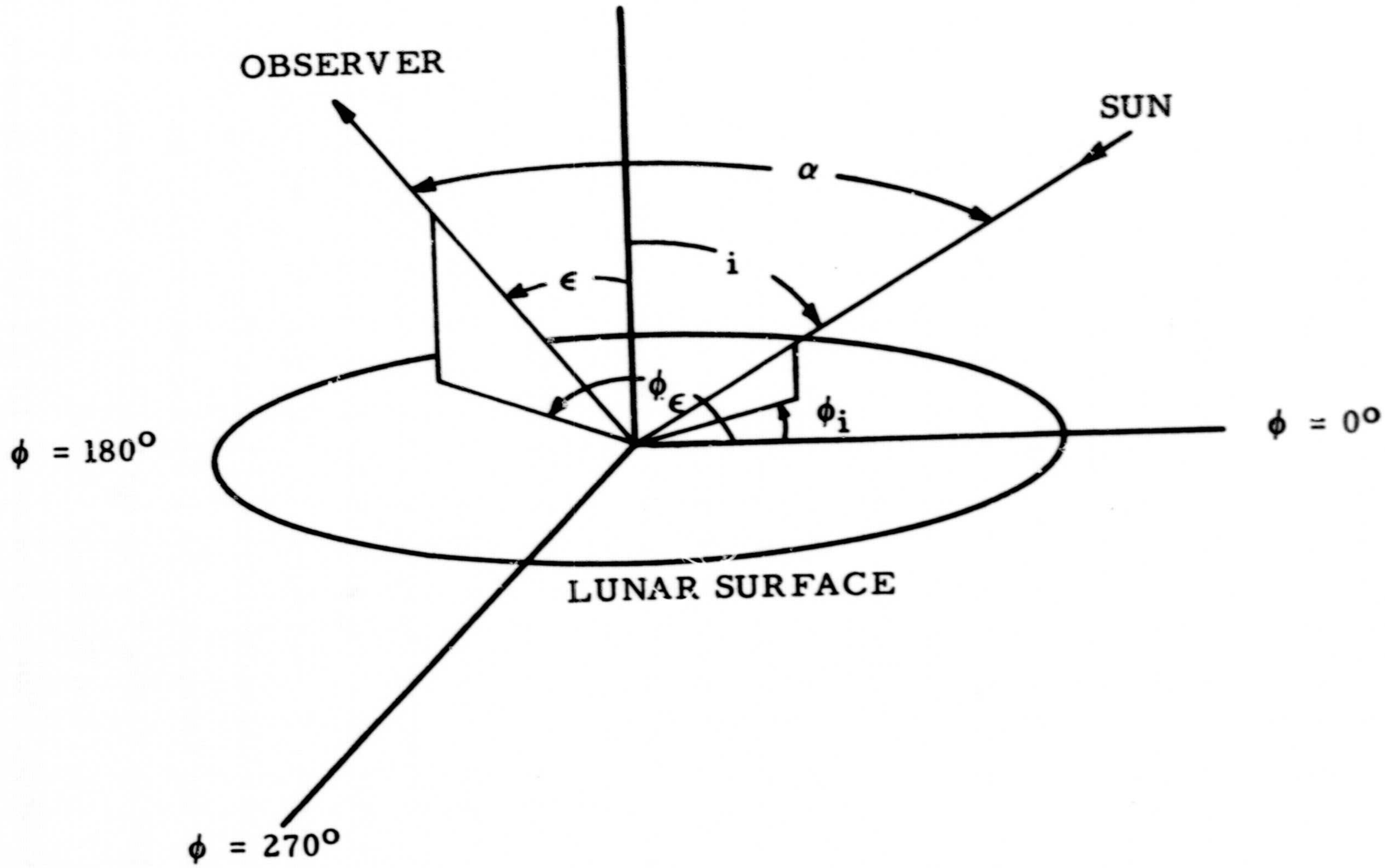

FIGURE 1. GEOMETRICAL DIAGRAM SHOWING ANGLES INVOLVED IN DISCUSSION AND CALCULATIONS

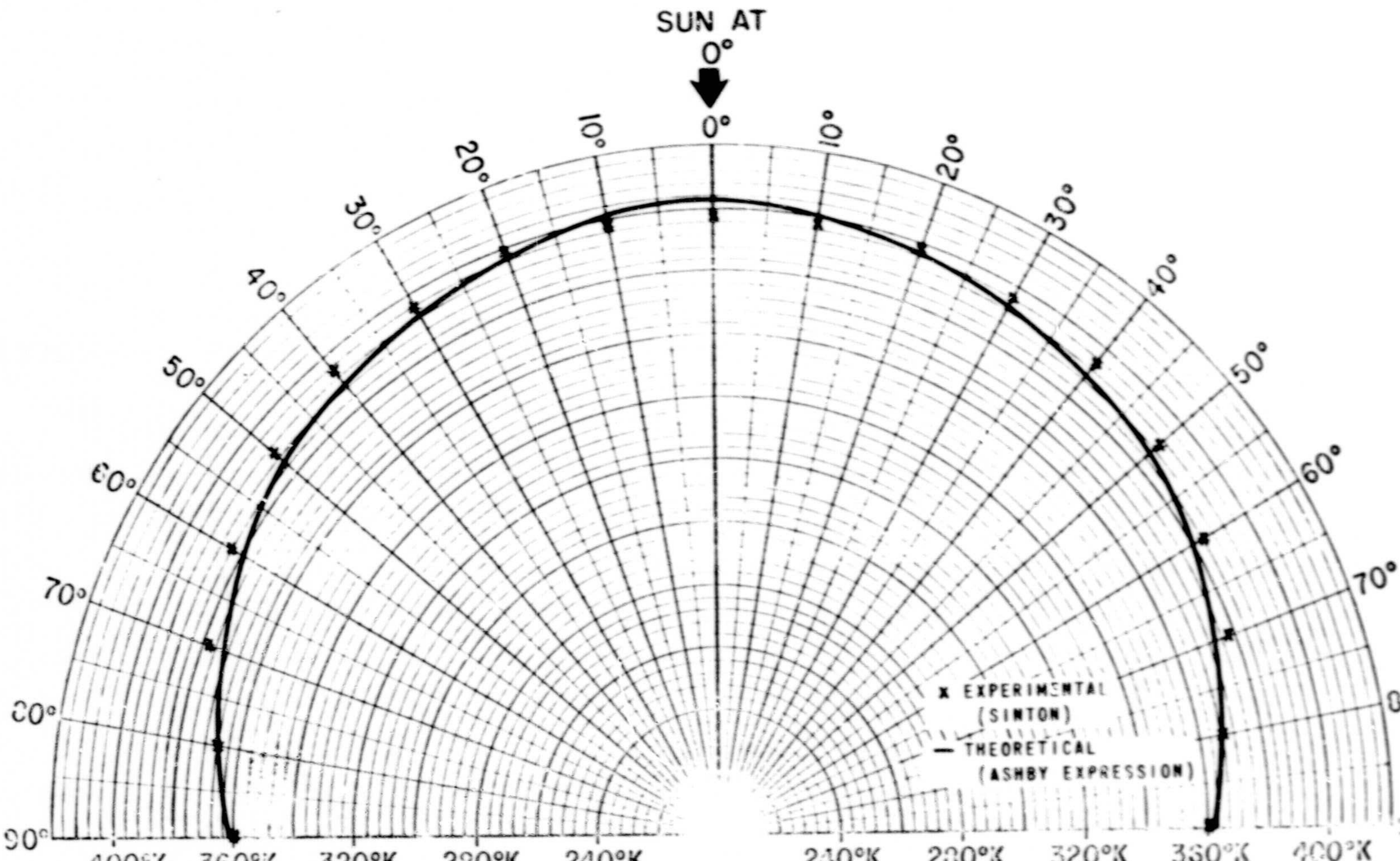

FIGURE 2. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 0°, $\phi_\epsilon = 0^\circ$

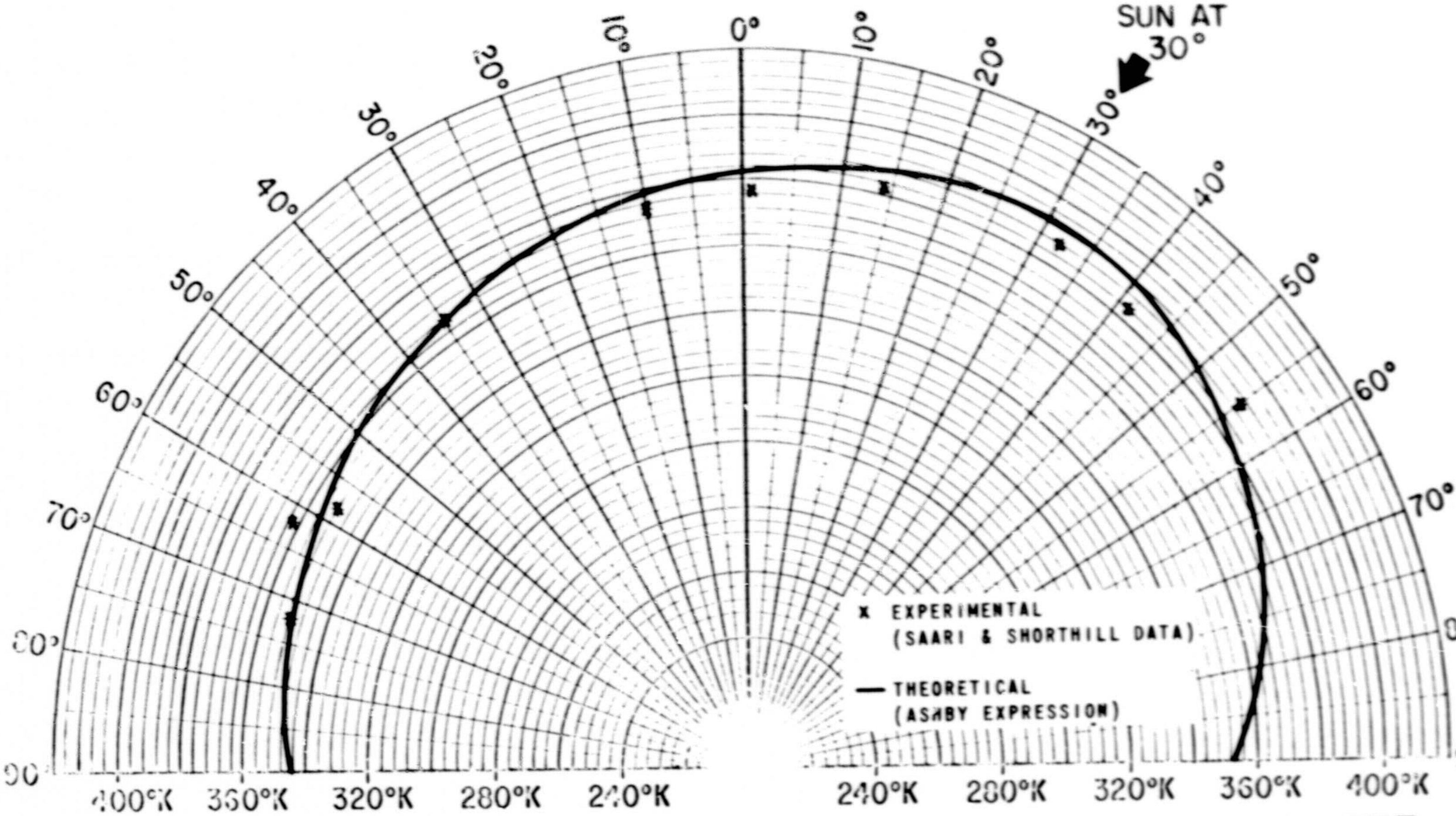

FIGURE 3. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 30°, $\phi_\epsilon = 0°$

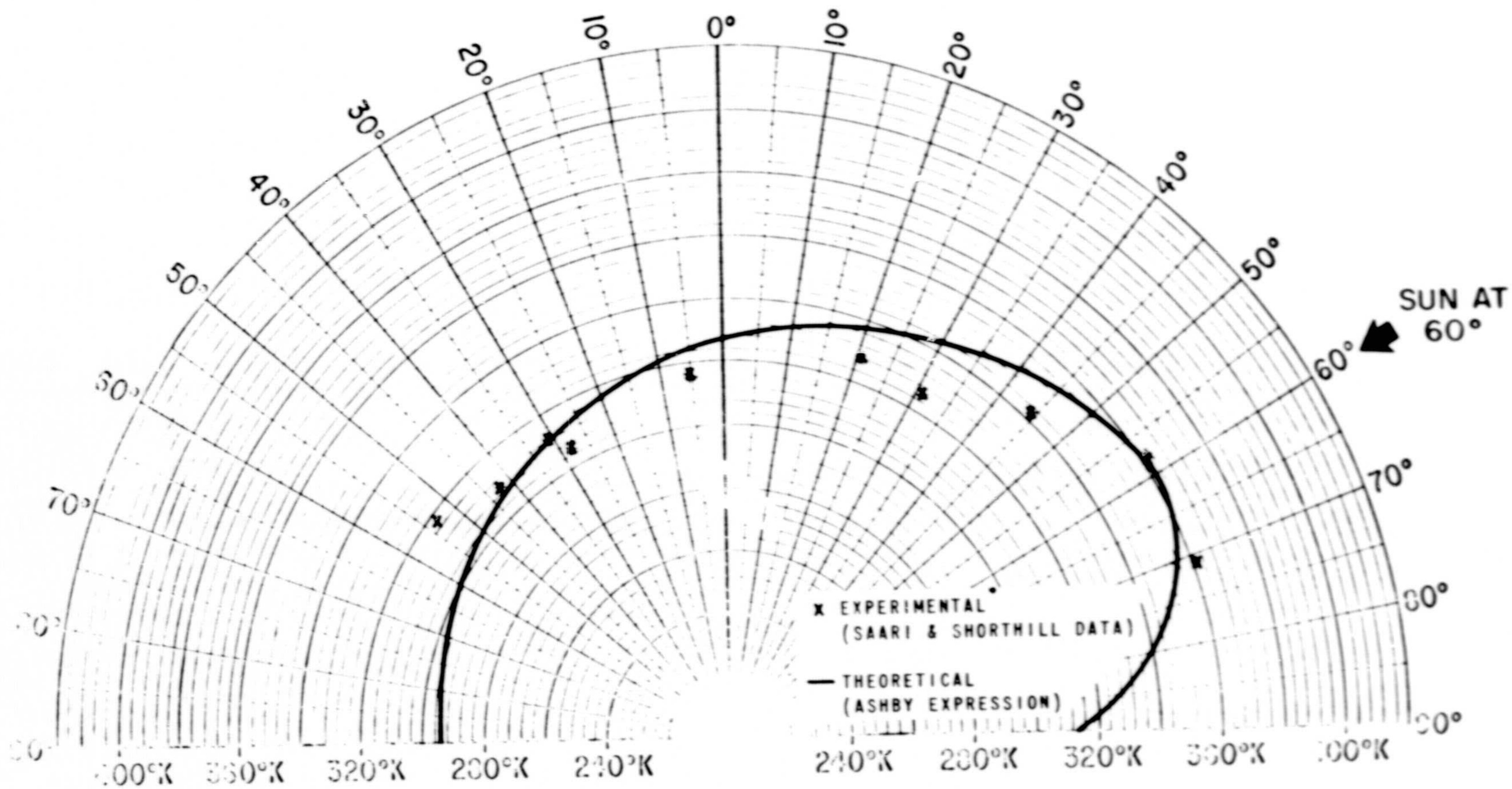

FIGURE 4. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 60°, $\phi_\epsilon = 0°$

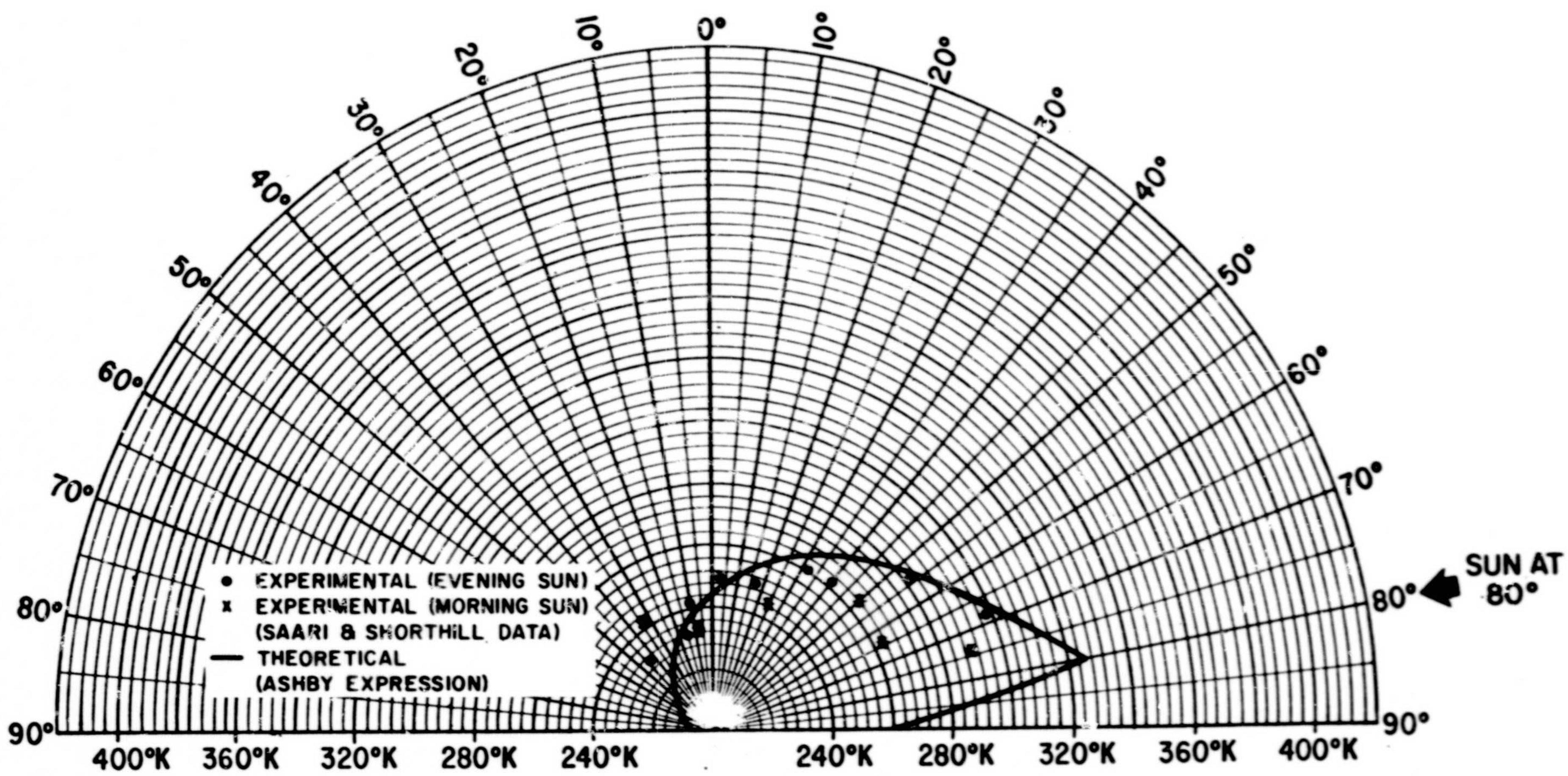

FIGURE 5. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 80°, $\phi_\epsilon = 0°$

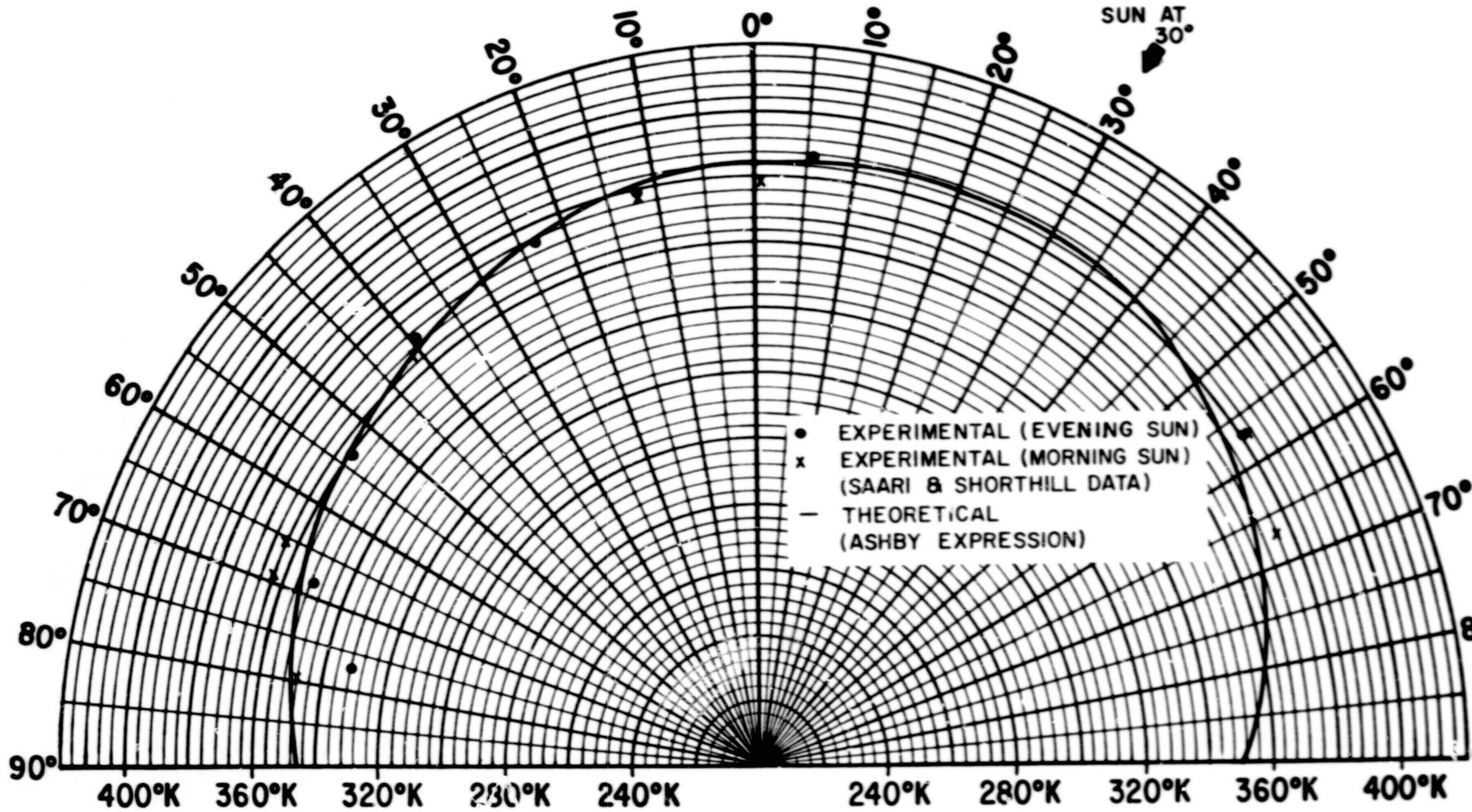

FIGURE 6. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 30°, $\phi_\epsilon = 45°$

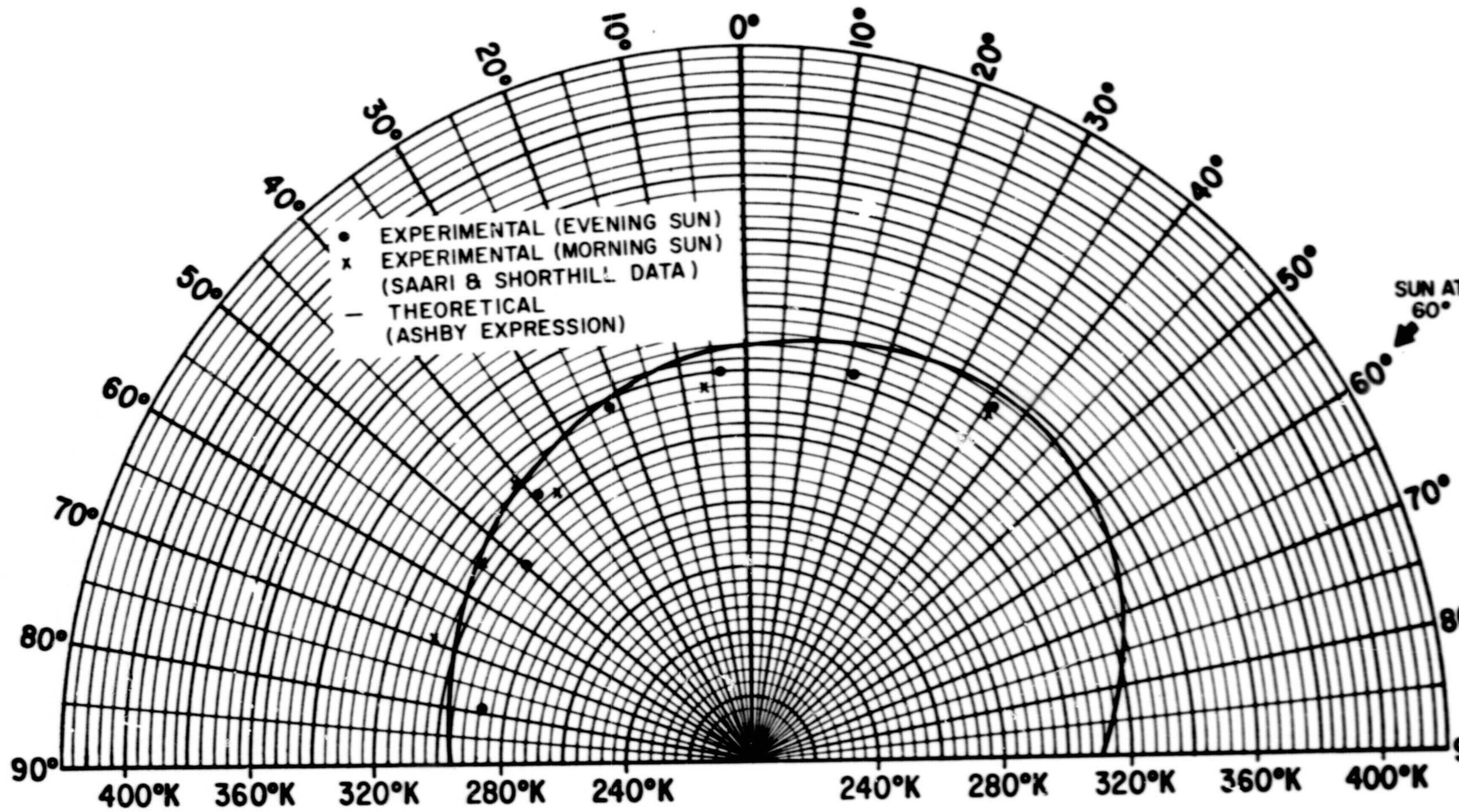

FIGURE 7. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 60°, $\phi_\epsilon = 45°$

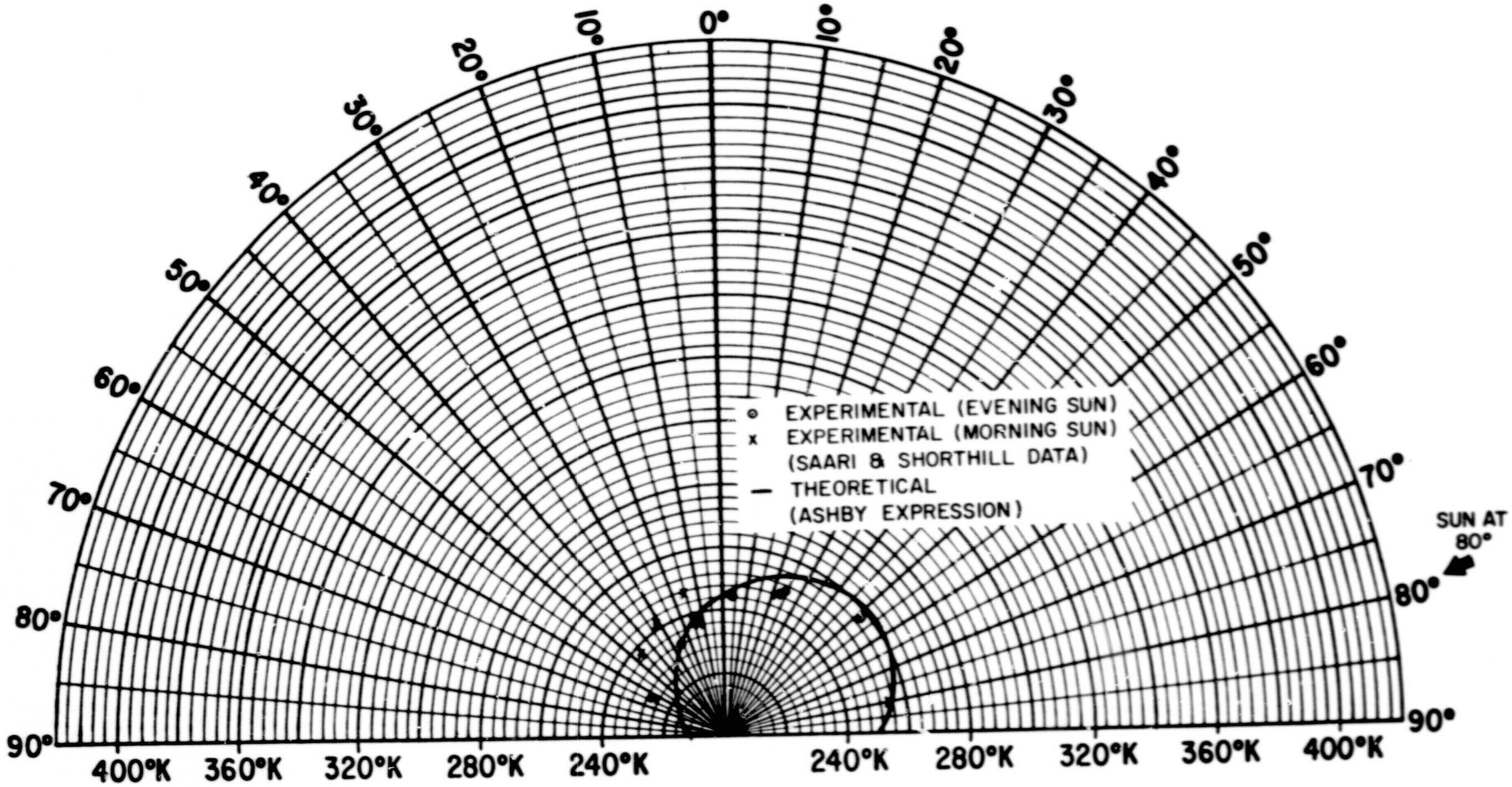

FIGURE 8. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 80°, $\phi_\epsilon = 45°$

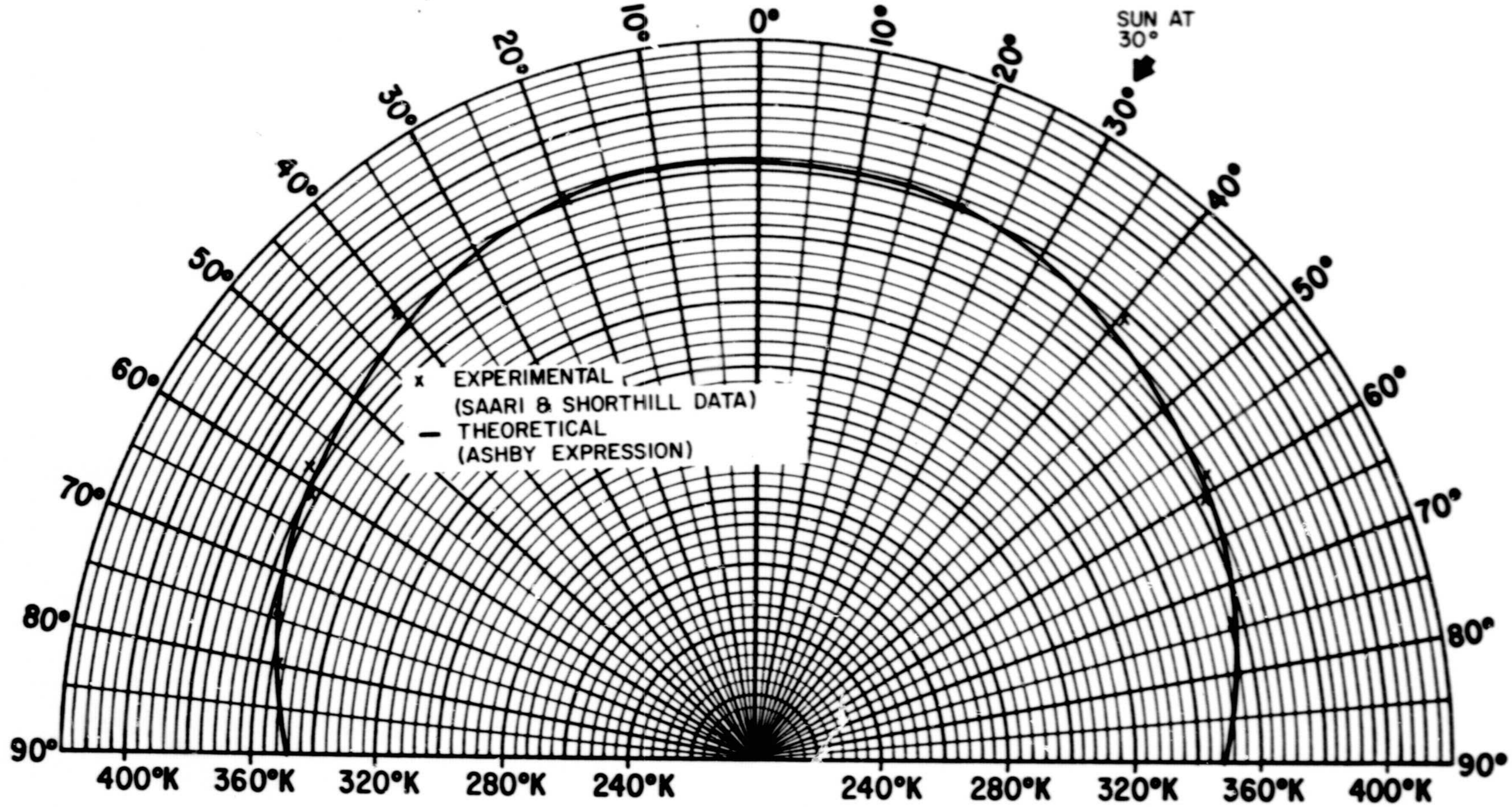

FIGURE 9. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SOLAR INCIDENCE ANGLE OF 30°, $\phi_\epsilon = 90^\circ$

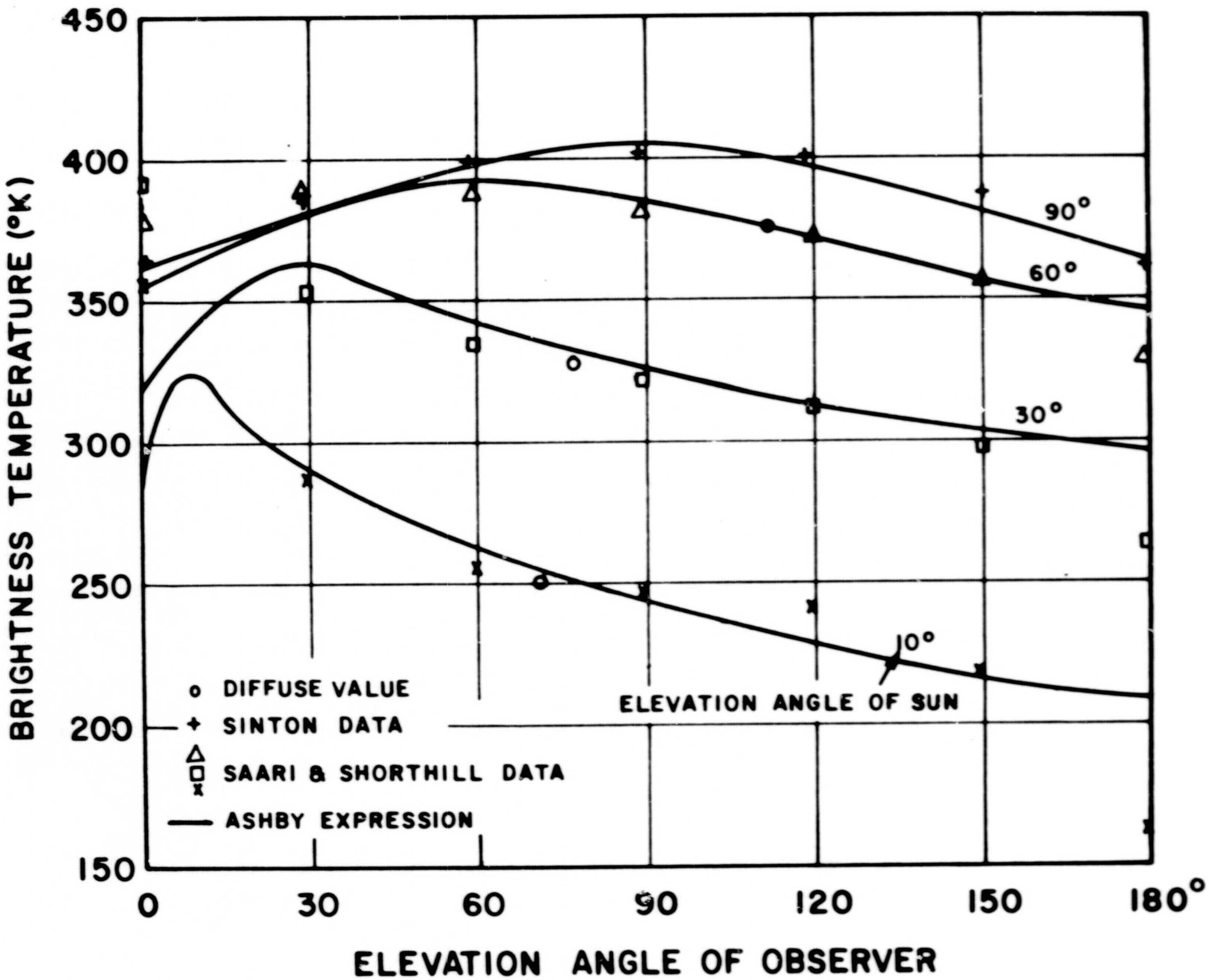

FIGURE 10. LUNAR BRIGHTNESS TEMPERATURE AS A FUNCTION OF THE ANGLE OF OBSERVATION FOR SEVERAL ELEVATION ANGLES OF THE SUN. (The elevation angles are measured from the lunar surface in the direction of sunrise and in the plane containing the sun vector and the normal to the lunar surface.)

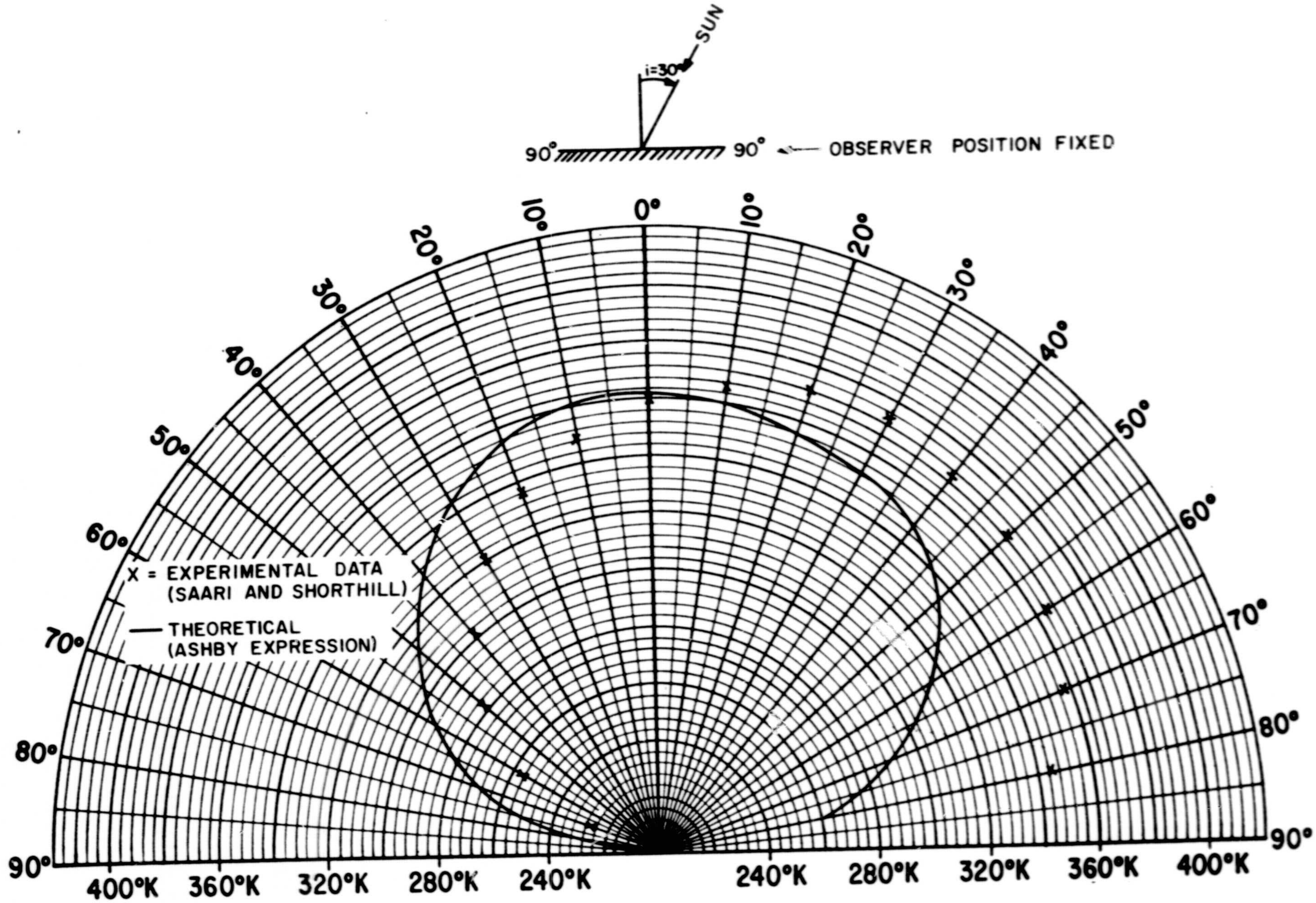

FIGURE 11. LUNAR LIMB BRIGHTNESS TEMPERATURE AT THERMAL EQUATOR. (The brightness temperature is plotted as a function of the solar incidence angle for the fixed observation angle of 90°.)

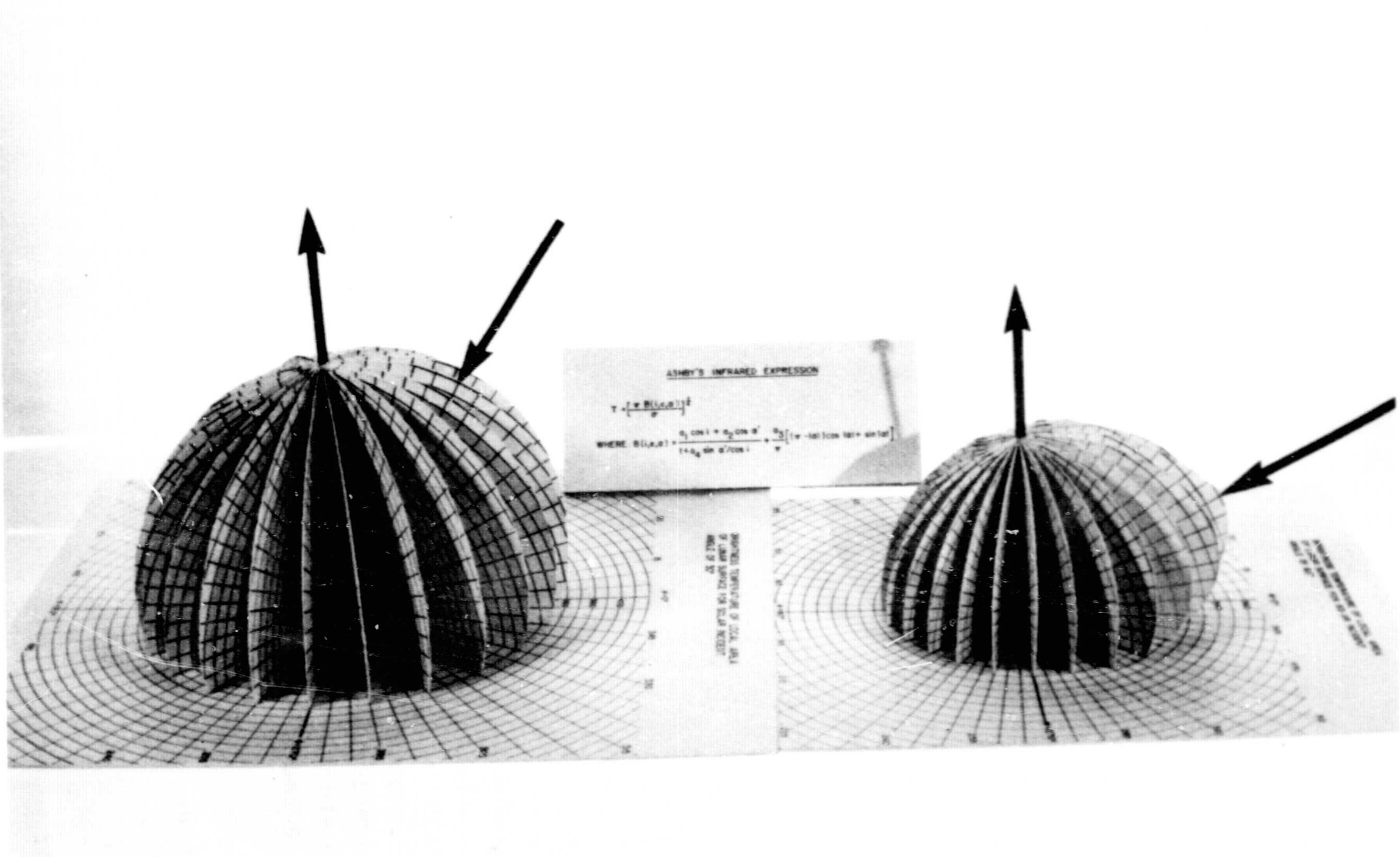

FIGURE 12. SUN ANGLES OF 30° AND 60° MEASURED FROM THE SURFACE NORMAL. (The size of the model indicates the magnitude of the temperatures.)