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RELATION BETWEEN THEORETICAL AND OBSERVATIONAL MODELS OF THE UPPER ATMOSPHERE

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Relation between Theoretical and Observational Models of the Upper Atmosphere

by

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In a previous paper [Harris and Priester (1962)] we published theoretical working models for the solar-cycle variation of the upper atmosphere based upon a working hypothesis concerning the dependence of the heat sources on the solar activity. Therein it was assumed - faute de mieux - that the fluxes of both heat sources (extreme ultraviolet flux and "corpuscular" heat flux) vary in proportion to the monthly averages of the solar 10.7 cm flux, which is generally used as an indicator of solar activity. Consequently the model parameters S of the theoretical models were taken equal to the monthly averages of the 10.7 cm flux.

In addition to the comparison made previously with data for high solar activity it is now possible to compare these models also with observational data obtained during times of medium and low solar activity. This leads to an improvement of the working hypothesis. The observational results used are the models by D.G. King-Hele (1963) for the years 1958/59, 1960, 1961 and 1962. An appreciably good agreement is found for all levels of solar activity in the comparison with the theoretical models if one regards how large the density changes are during the solar cycle. Towards the lowest level of solar activity, however, a systematic deviation appears. This yields an empirical relation between the monthly averages of the solar 10.7 cm flux $\overline{F}$ and the model parameters S which is shown in Fig. 1. This relation now replaces the working hypothesis used previously, and any user of our theoretical models should take the appropriate model according to this relation. The data given by D.G. King-Hele (1963) are yearly averages,

which are not corrected for the semiannual and annual variation [H.K.Paetzold (1963)]. Our theoretical models on the other hand are generally applicable to average values for the months September through December. This is due to the fact that the observational model by H.A.Martin et al.(1961), on which the theoretical models are based, apply to the average densities of the months given above. Therefore one may consider the curve in Fig. 1 as a lower limit. In particular the open circles for $\overline{F} = 150$ and 100 might be placed slightly too low. A more refined analysis is presently being carried out by M.Roemer (1963).

In Fig. 2 to 5 the comparison is shown between the observational and theoretical models utilizing the new relationship. The observational day time maximum curve in Fig. 2 belongs to the year 1958 where the average of the solar 10.7 cm flux was 230. This accounts for the deviation from the theoretical model for an average flux of 200.

In Fig. 3 the merging of the observational curves for day time and night time at 300 km is believed to be influenced by the method of extrapolation to lower altitudes. Theoretical considerations [Harris and Priester (1962)] make a cross over between day and night curve very unlikely at an altitude as high as 300 km. Furthermore, L.G.Jacchia and J.Slowely (1962) found an appreciably larger diurnal amplitude at 350 km from Explorer I for the year 1960.

In Fig. 4 it is seen that towards low solar activity the diurnal amplitude increases at low altitudes (300 km). The theory shows that this phenomenon follows from the lowering of the atomic oxygen layer during the decreasing phase of solar activity.

The pronounced increase of the scale height at higher altitudes (above 600 km) (as seen in Fig 4) can be explained by the lowering of the helium layer. The smaller diurnal amplitude in the observational curves above 600 km indicates that a greater amount of helium must be present than assumed in the theoretical models. M.Roemer (1963) finds a better agreement with data obtained from Echo I when using a theoretical model which has a 2.5 times greater amount of helium [I.Harris (1963)] than in the theoretical models mentioned above. In Fig. 5 densities of this new model for S = 100 are compared with the appropriate data by King-Hele. The agreement between theory and observations is obviously even better as in Fig. 4. In the models for higher levels of solar activities (S = 150) no noticeable increase of densities for heights up to 700 km occurs due to the increase of the number density N of helium by a factor of 2.5 at the boundary [$N(He)=6.25 \cdot 10^{7}$ cm^{-3} at an altitude of 120 km]. For this reason Fig. 2 and 3 are also applicable for the new models.

Also shown in Fig. 4 and 5 is a result obtained by Explorer XVII [R.Horowitze et al. (1963)] which fills a gap in our knowledge at low altitudes (below 300 km) for times of low solar activity. At 21:00 hours local time, on April 3, 1963 at 260 km altitude and temperate latitudes the measured density was $2.7 \cdot 10^{-14}$ $g \cdot cm^{-3}$. The average solar 10.7 cm flux was about 75 in the usual units. Thus, using the relation shown in Fig. 1 a theoretical model with parameter S = 100 is applicable.

If one plots the nighttime- and daytime- temperatures of the theoretical models using the new empirical relation (Fig. 1) one obtains an excellent

agreement with the nighttime-temperatures derived by L.G.Jacchia (1963) who used M.Nicholet's (1961) models for the conversion of observed densities into temperatures (Fig. 6). The daytime temperatures show a systematic difference of about 100 to 150 ^{o}K. This could be explained by two reasons: 1) For a given density at any height Nicholet's models furnish one value for the temperature independent of local time contrary to the Harris-Priester models, where the relation between density and temperature at a given height depends on local time (Fig. 7). This is due to the fact that the latter models are solutions of the time-dependent heat conduction equation. Therefore the use of Nicolet's models for conversion of density into temperature would lead to a diurnal temperature amplitude which is too small. The difference depends on the altitude and the level of solar activity. For the data used by L.G.Jacchia the difference may be estimated to be about 50 to 100 ^{o}K. 2) The theoretical models of Harris and Priester are based on the observational model of Bonn Observatory 1961 [H.A.Martin et al. (1961)]. There are indications that the diurnal amplitude in this model is slightly too large, which again can account for a difference of 50 to 100 ^{o}K.

Conclusions: The comparison with air densities observed within the period from 1958 to 1963 has shown that the theoretical models give a good representation of the atmospheric properties and their changes during the decreasing phase of solar activity if the relation given in Fig. 1 is used. A still better agreement is obtained if in the theoretical models the amount of helium is increased by a factor of 2.5 at the boundary of 120 km. This, however, is important for periods of very low solar activity only.

Further comparisons with forthcoming data for the years 1965 through 1968 will reveal whether the same empirical relation holds also for the increasing phase of the 11-year cycle.

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Captions of Figures

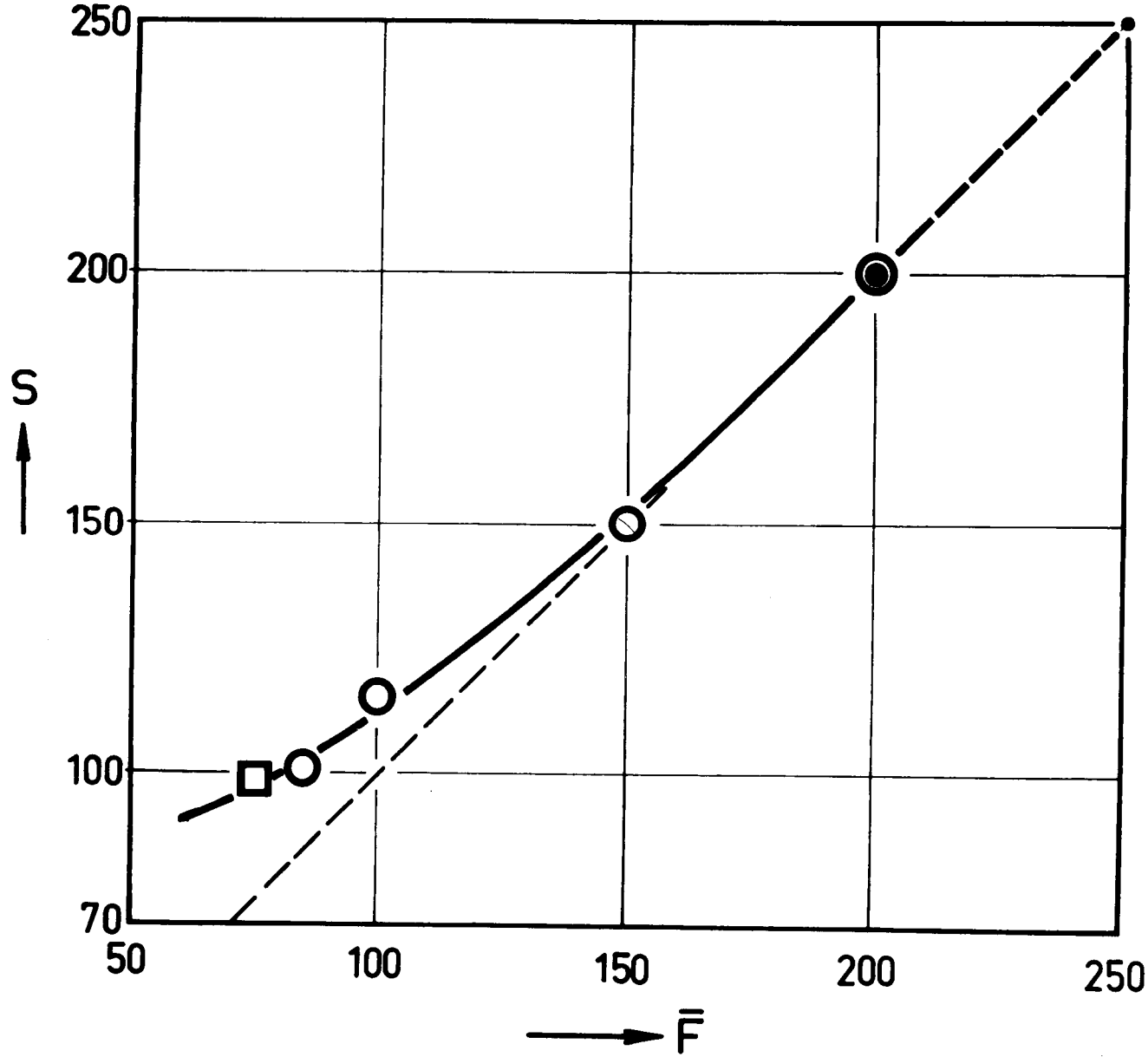
Fig. 1: Empirical relation between H.-P. model number S and the monthly averages of the solar 10.7 cm-flux $\bar{F}$ as obtained from comparison with observational data: open circles: models by D.G.King-Hele for 1958/59, 1960, 1961, 1962; square: First data by Explorer XVII, launched April 2, 1963; filled circle: Bonn model for $\bar{F}$=200. The dotted straight line represents the preliminary working hypothesis used in the paper by Harris and Priester (1962).

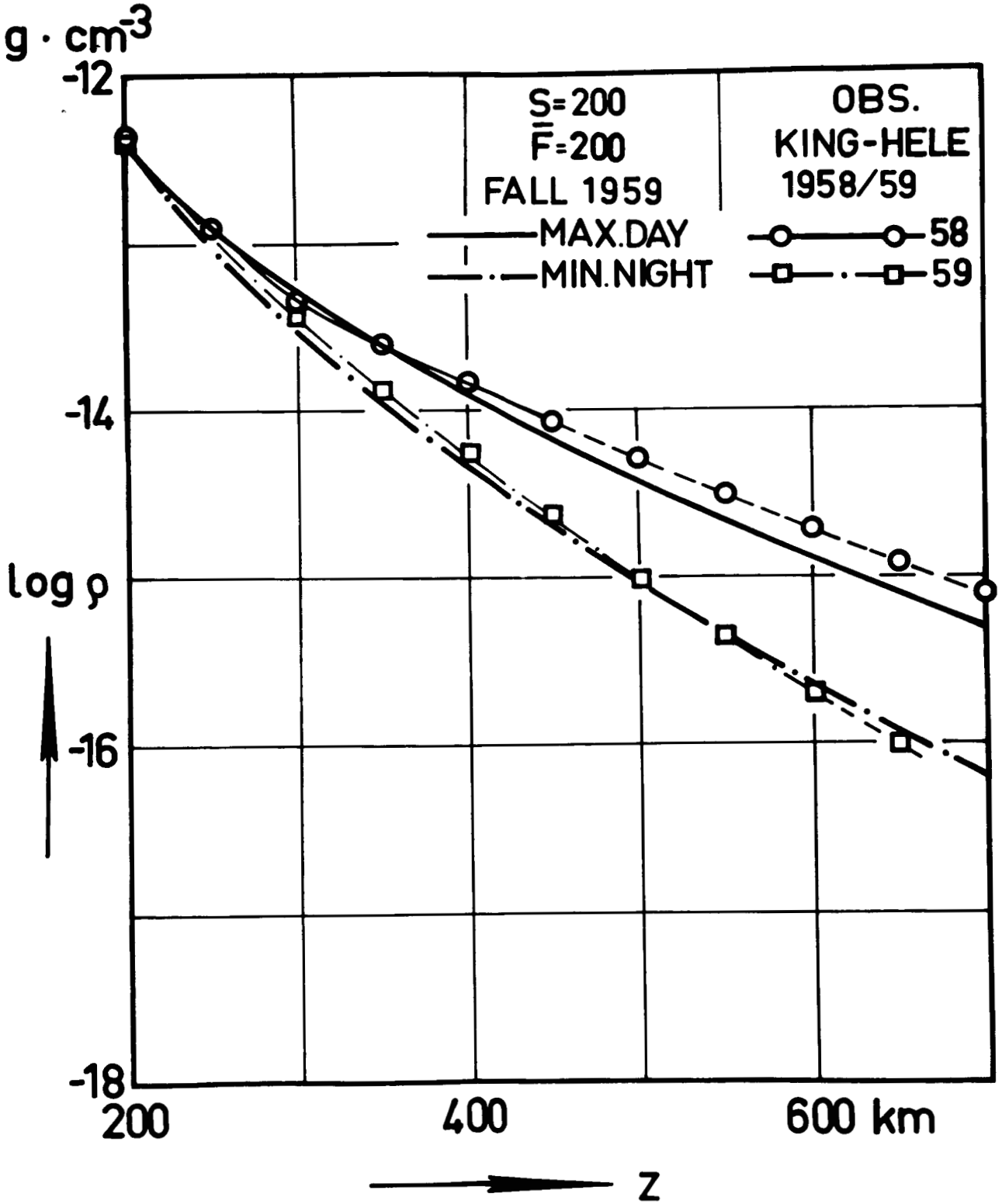
Fig. 2 - 4: Maximum daytime and minimum nighttime densities obtained by D.G. King-Hele from a large number of Satellites are compared with the corresponding theoretical models by Harris and Priester. In Fig. 4 the density measured on April 3, 1963, 21:00 hours local time by Explorer XVII is also given.

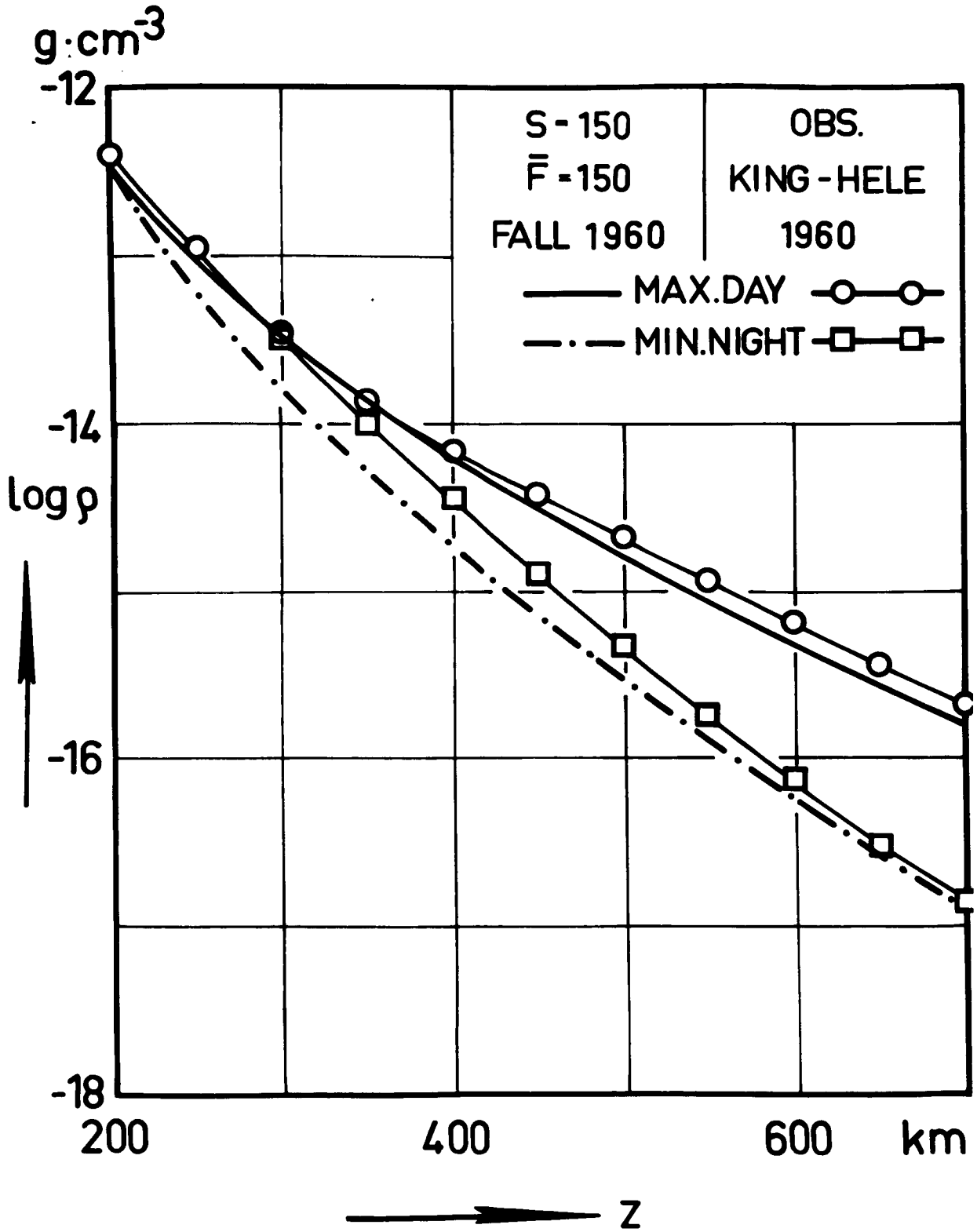
Fig. 5: Comparison between King-Hele's observed densities for 1962 with a new theoretical model containing an amount of helium increased by a factor 2.5 with regard to the previous models. As in Fig. 4 the density obtained by Explorer XVII is also given.

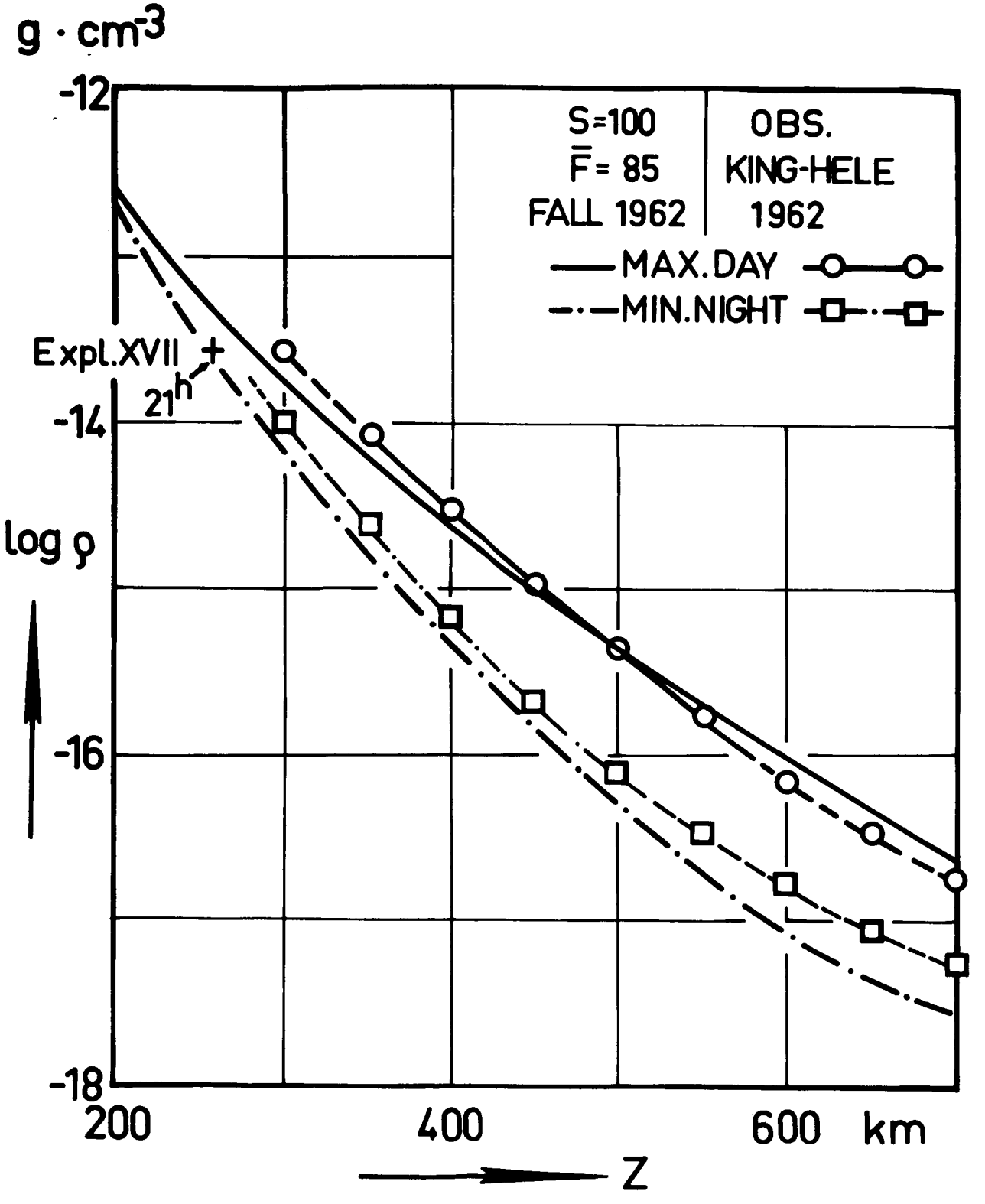
Fig. 6: Relation between exospheric temperature and the monthly averages of the solar 10.7 cm-flux $\bar{F}$. The dots and small circles represent satellite drag data by L.G.Jacchia (1963) for night- and day-time respectively. The temperatures are derived using Nicholet's model. The large circles give the temperatures of H.-P. models for 4 and 14 hours local time based on the empirical relation (Fig. 1).

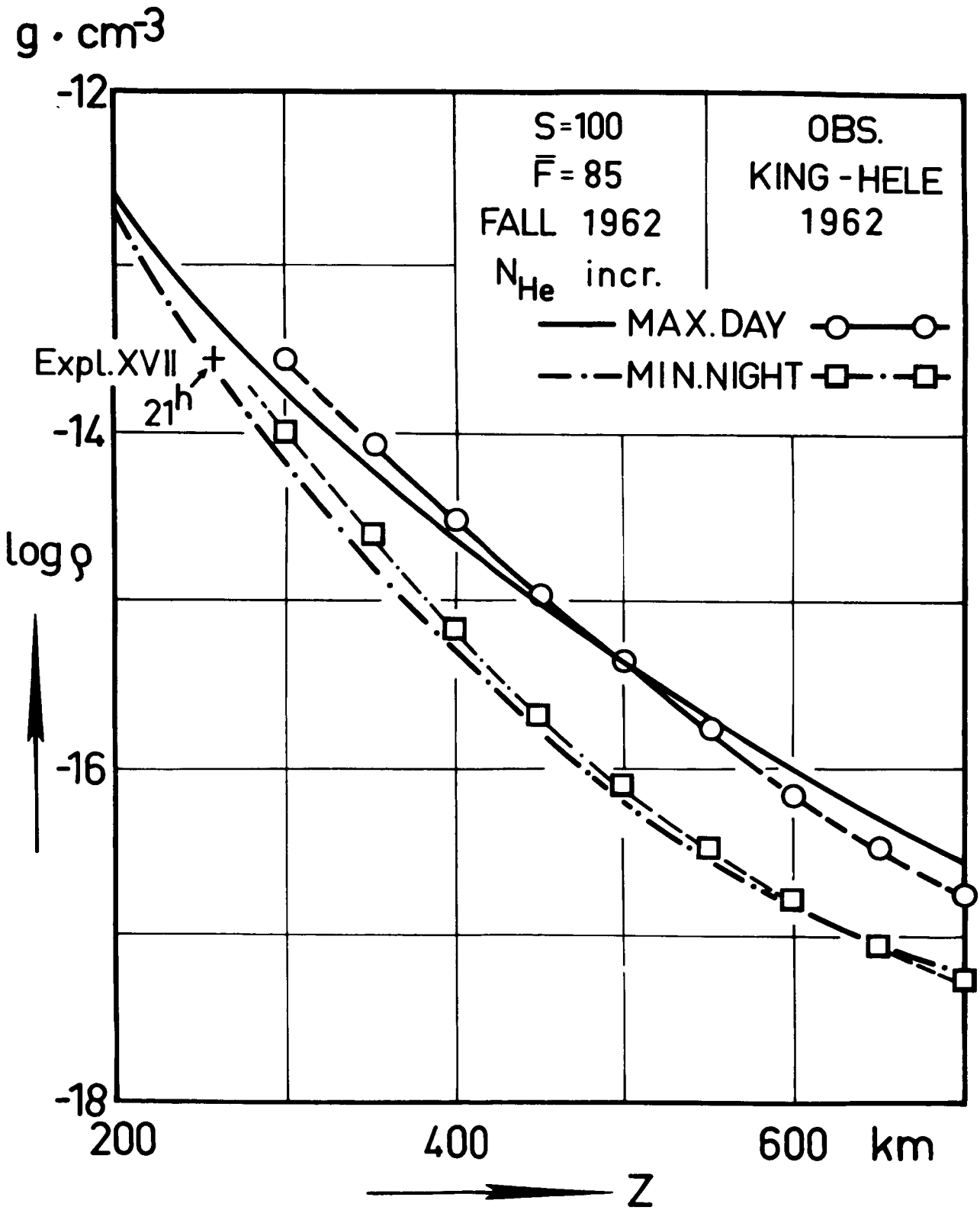
Fig. 7: Relation between density and temperature for eight different heights from 200 to 1000 km according to the Harris-Priester models for 4:00 and 14:00 hours local time (thick lines) and accourding to Nicolet's model (thin line).

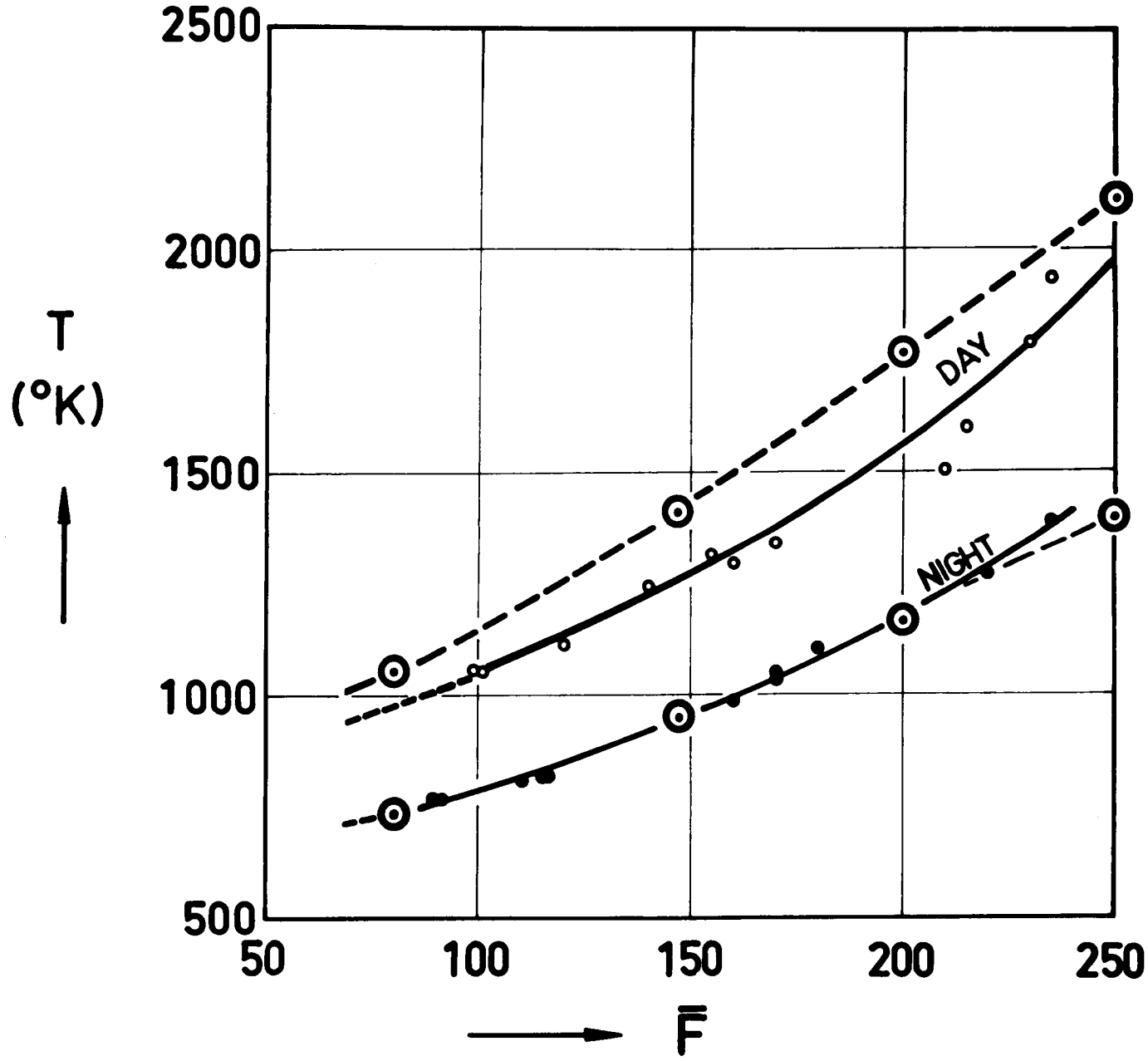

250
200
150
100
70
S
50
100
150
200
250
F̄

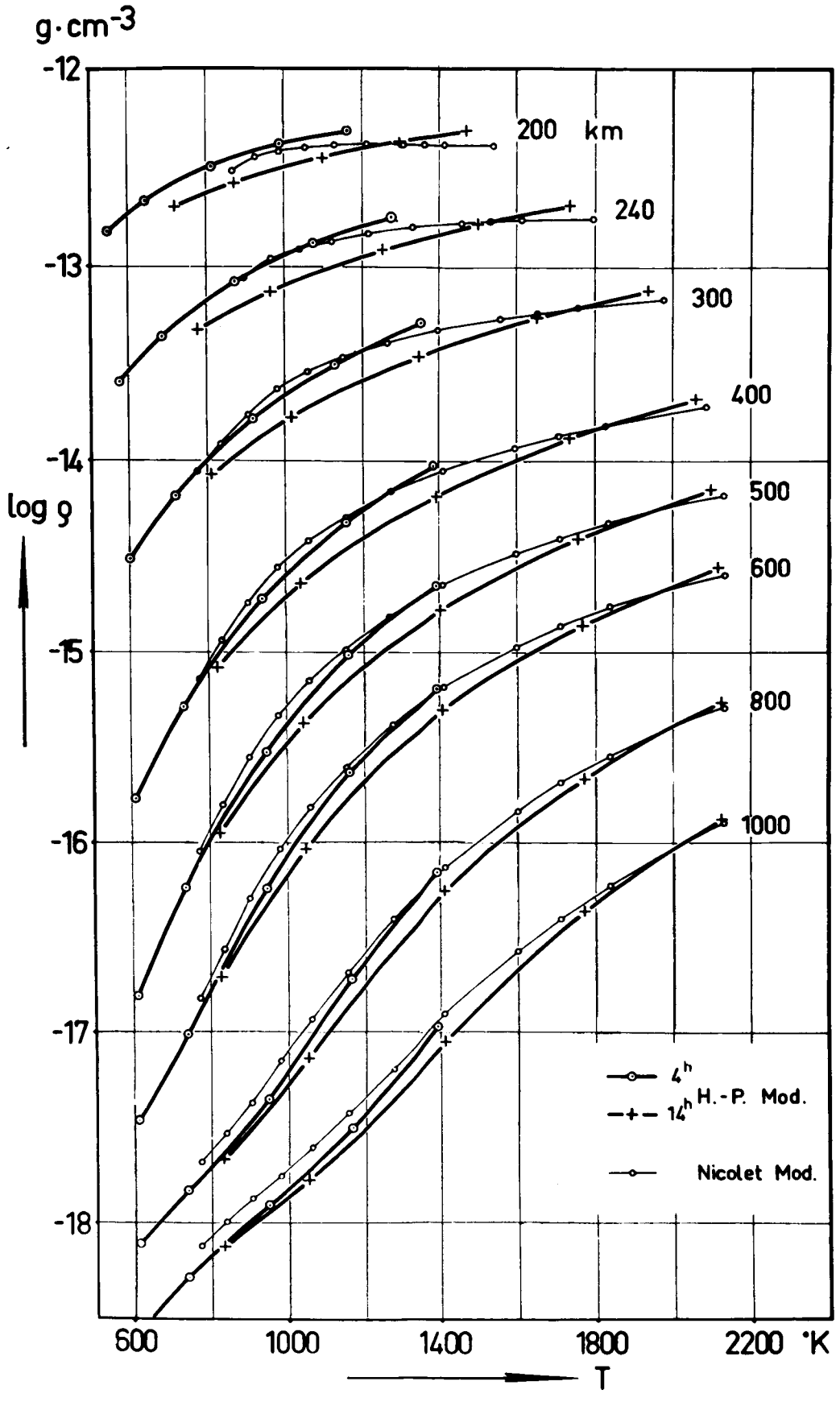

g · cm⁻³
-12
-14
-16
-18
log ρ
S=200
F̄=200
FALL 1959
MAX.DAY
MIN.NIGHT
OBS.
KING-HELE
1958/59
58
59
200
400
600 km
Z


g·cm⁻³
-12
-14
log ρ
-16
-18
200
400
600
km
z
S - 150
F̄ - 150
FALL 1960
OBS.
KING - HELE
1960
MAX.DAY
MIN.NIGHT


g · cm-3
-12
-14
-16
-18
log ρ
S=100
F̄= 85
FALL 1962
OBS.
KING-HELE
1962
MAX. DAY
MIN. NIGHT
Expl. XVII
21h
200
400
600
km
Z


g · cm-3
-12
-14
-16
-18
log ρ
S=100
F̄=85
FALL 1962
N_He incr.
OBS.
KING-HELE
1962
MAX.DAY
MIN.NIGHT
Expl.XVII
21h
200
400
600
km
Z


2500
2000
1500
1000
500
T
(°K)
DAY
NIGHT
50
100
150
200
250
F


g·cm⁻³
-12
-13
-14
-15
-16
-17
-18
log ρ
200 km
240
300
400
500
600
800
1000
4h
14h H.-P. Mod.
Nicolet Mod.
600
1000
1400
1800
2200 °K
T