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MOLLIER DIAGRAM FOR NITROGEN

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ABSTRACT

Thermodynamic data for nitrogen are presented in Mollier diagram form covering the temperature range of 30 °K to 15, 000 °K and the density range of 10^{-6} to 10^{3} atmospheres.

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CONTENTS

ILLUSTRATIONS

NOMENCLATURE

c_p	Specific heat at constant pressure
H	Specific enthalpy
°K	Degree Kelvin
log	Logarithm to the base 10
P	Pressure in relative atmospheres
R	Gas constant for nitrogen
°R	Degree Rankine
S	Specific entropy
T	Temperature in °K
v	Specific volume $(1/\rho)$
ρ/ρ_o	Density ratio
ρ_o	Reference density at one atmosphere pressure, 273.16 °K

CONVERSION FACTORS

Standard atmospheric pressure

P_o = 760 mm Hg
29.921 in. Hg
10332 kg/m^2
14.696 psia
2116 psfa

Reference density

ρ_o = 1.25046 x 10^{-3} g/cm^3
4.46338 x 10^{-5} moles/cm^3
1.25050 g/liter
4.51760 x 10^{-5} lb/in.^{3}
7.80641 x 10^{-2} lb/ft^3
2.42435 x 10^{-3} slugs/ft^3

Temperature

T (°K) x 1.8 = T (°R)
T (°K) = T (°C) + 273.16
T (°R) = T (°F) + 459.69

To Change	To	With Units of	Multiply by
$\frac{H}{R}$ (°K)	$\frac{H}{RT}$	none	$\frac{1}{T\ (°K)}$
	$\frac{H}{R}$	°R	1.8
	H	$\frac{ft^2}{sec^2}$	3196.66
		$\frac{BTU}{lb}$	0.12768
		$\frac{cal}{g}$	0.0709305
$\frac{S}{R}$	S	$\frac{ft^2}{sec^2\ °K}$	3196.66
		$\frac{ft^2}{sec^2\ °R}$	1775.92
		$\frac{BTU}{lb\ °R}$	0.07093
		$\frac{BTU}{lb\ °K}$	0.12768
		$\frac{cal}{g\ °K}$	0.0709305

INTRODUCTION

This nitrogen Mollier diagram includes all of the data available from the three sources listed in the references. It consists of an index sheet and 28 individual sections. The temperature ranges from 30° K to 15,000° K, and the diagram includes data for the solid and liquid nitrogen lines at very low temperatures. The density range extends from 10^{-6} to 10^{3} relative atmospheres.

DISCUSSION

EXTENT AND SOURCES OF THE NITROGEN MOLLIER DIAGRAM

This Mollier diagram covers the region between 30 °K and 15,000 °K. The following table demonstrates the scope of the diagram.

Scope of the Nitrogen Mollier Diagram

T	ρ	P	S/R	Source
2000 °K to 15000 °K	10^{3} atm to 10^{-6} atm	2×10^{4} atm to 10^{-5} atm	21 to 121	Refs. 1 and 2
100 °K to 2000 °K		10^{2} atm to 10^{-2} atm	19 to 35	Ref. 3
30 °K to 100 °K		1 atm to 10^{-2} atm	19 to 24	Perfect gas laws
30 °K to 2000 °K		10^{-2} atm to 10^{-6} atm	21 to 43	Extrapolation (see text)

The sources used to compile this diagram were the recent preliminary nitrogen tables (Refs. 1 and 2) by Hilsenrath for temperatures above 2000°K and "Tables of Thermal Properties of Gases" (Ref. 3) for temperatures below 2000°K. The two sources differ by about two percent at 2000°K and pressures above 70 atmospheres. This difference is a result of van der Waal's forces being accounted for in the data of Ref. 3

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and not in Refs. 1 and 2, but it is unnoticeable in the diagram where the two sources meet.

The Hilsenrath data (Refs. 1 and 2) above 2000°K give the properties of the equilibrium mixture treated as an ideal gas. Van der Waal's effects have not been accounted for in this region.

Reference 3 data below 2000°K are restricted to the pressure range of 100 to 0.01 atm, and no data below 100°K are given. Pressure and density data below 0.01 atm of pressure were obtained by extrapolation of the known data. This was done by plotting at constant temperature the logarithm of the pressure and density against dimensionless entropy (S/R). These extrapolations can be justified at low pressures and temperatures from perfect gas relationships. The three equations derived in the appendix using Bridgman's tables (Ref. 4) indicate that the extrapolations are straight lines. Plots of the available data indicate that these relationships are valid to about 100 atm of pressure.

Enthalpy-temperature data below 100°K were obtained by using the perfect gas relationship

$$H/R = (c_p/R)\ T$$

where c_p/R was taken to be 3.500. The liquefaction line, triple point, and the solidification line were plotted from data given in Ref. 3. Near this area caution should be used in the interpretation of the temperature, pressure, and density lines. These properties are based upon the perfect gas laws and may not accurately represent the true behavior of the gas in this region.

THE FORMAT OF THE NITROGEN MOLLIER DIAGRAM

For convenience and to obtain a scale that would allow accurate reading, the diagram was plotted in sections on 8 1/2 x 11 in. semilog paper. A master index sheet (Fig. 1) has been made which shows the regions covered by each section and the entire diagram.

Dimensionless numbers were used as much as possible to obtain a greater amount of flexibility in the use of the diagram. Entropy was plotted in the dimensionless form S/R. Pressure was plotted in relative atmospheres, and the density in the logarithm to the base 10 of the density ratio ρ/ρ_o. The enthalpy function H/R was used to give an appropriate scale and to simplify conversion. H/R, as used here, has the units of °K so that H/RT is dimensionless since temperature is given in °K. The conversion tables show conversions of the enthalpy function H/R and the entropy function S/R to common engineering units.

Each of the individual sections was plotted with great care to maintain as much of the reliability of the sources as possible. The functions were plotted at close enough intervals so that interpolation on a linear basis should give satisfactory results.

REFERENCES

1. Hilsenrath, J. "A First Approximation to the Thermodynamic Properties of Nitrogen." National Bureau of Standards, Preliminary Draft, May 1959.

2. Hilsenrath, J., Addition to Ref. 1 covering the density range from 100 to 1000 relative atmospheres. Communication to Dr. Martin Grabau, December 1959.

3. Hilsenrath, J., Beckett, C. W., et al. "Tables of Thermal Properties of Gases." National Bureau of Standards Circular 564, November 1955.

4. Bridgman, P. W. A Condensed Collection of Thermodynamic Formulas. Harvard University Press, Cambridge, Massachusetts, 1925.

APPENDIX

Derivation of the equations used as the basis for extrapolation at low pressures and temperatures

1. Show that

$$\left(\frac{\partial H}{\partial S}\right)_T = 0:$$

$$\left.\begin{aligned}(\partial H)_T &= -v + T\left(\frac{\partial v}{\partial T}\right)_P\\ (\partial S)_T &= \left(\frac{\partial v}{\partial T}\right)_P\end{aligned}\right\}\text{ Bridgman Tables}$$

$$\left(\frac{\partial H}{\partial S}\right)_T = \frac{-v}{(\partial v/\partial T)_P} + T$$

from the equation of state

$$v = \frac{RT}{P}$$

$$\left(\frac{\partial v}{\partial T}\right)_P = \frac{R}{P}$$

$$P = \frac{RT}{v}$$

$$\left(\frac{\partial v}{\partial T}\right)_P = \frac{R}{RT/v} = \frac{v}{T}$$

$$\left(\frac{\partial H}{\partial S}\right)_T = -\frac{v}{v/T} + T = -T + T$$

$$\left(\frac{\partial H}{\partial S}\right)_T = 0$$

2. Show that

$$\left(\frac{\partial \, Ln \, P}{\partial S}\right)_T = C \text{ (constant) :}$$

$$P = v^{-1} R T$$

$$Ln \, P = Ln \, R T - Ln \, v$$

$$\left(\frac{\partial \, Ln \, P}{\partial v}\right)_T = -\frac{1}{v}$$

$$\left.\begin{aligned} (\partial v)_T &= -(\partial v/\partial P)_T \\ (\partial S)_T &= (\partial v/\partial T)_P \end{aligned}\right\} \text{ Bridgman Tables}$$

$$\left(\frac{\partial v}{\partial S}\right)_T = \frac{-(\partial v/\partial P)_T}{(\partial v/\partial T)_P}$$

$$\left(\frac{\partial \, Ln \, P}{\partial S}\right)_T = \left(\frac{\partial \, Ln \, P}{\partial v}\right)_T \left(\frac{\partial v}{\partial S}\right)_T = \frac{(\partial v/\partial P)_T}{v \, (\partial v/\partial T)_P}$$

from the equation of state

$$v = \frac{R T}{P}$$

$$\left(\frac{\partial v}{\partial P}\right)_T = -R T P^{-2}$$

$$\left(\frac{\partial v}{\partial T}\right)_P = \frac{R}{P}$$

$$\left(\frac{\partial \, Ln \, P}{\partial S}\right)_T = \frac{-R T P^{-2}}{(R T P^{-1})(R P^{-1})}$$

$$\left(\frac{\partial \, Ln \, P}{\partial S}\right)_T = -\frac{1}{R} = \text{constant}$$

3. Show that

$$\left(\frac{\partial \, Ln \, \rho}{\partial S}\right)_T = C \text{ (constant)}:$$

$$\rho = \frac{P}{R\,T}$$

$$Ln \, \rho = Ln \, P - Ln \, R\,T$$

$$\left(\frac{\partial \, Ln \, \rho}{\partial P}\right)_T = \frac{1}{P}$$

$$\left.\begin{aligned} (\partial P)_T &= -1 \\ (\partial S)_T &= (\partial v/\partial T)_P \end{aligned}\right\} \text{Bridgman Tables}$$

$$\left(\frac{\partial P}{\partial S}\right)_T = -\left(\frac{\partial T}{\partial v}\right)_P$$

$$\left(\frac{\partial \, Ln \, \rho}{\partial S}\right)_T = \left(\frac{\partial \, Ln \, \rho}{\partial P}\right)_T \left(\frac{\partial P}{\partial S}\right)_T$$

$$= -\frac{1}{P}\left(\frac{\partial T}{\partial v}\right)_P$$

from the equation of state

$$T = \frac{P\,v}{R}$$

$$\left(\frac{\partial T}{\partial v}\right)_P = \frac{P}{R}$$

$$\left(\frac{\partial \, Ln \, \rho}{\partial S}\right)_T = -\frac{1}{P}\left(\frac{P}{R}\right)$$

$$\left(\frac{\partial \, Ln \, \rho}{\partial S}\right)_T = -\frac{1}{R} \text{ (constant)}$$

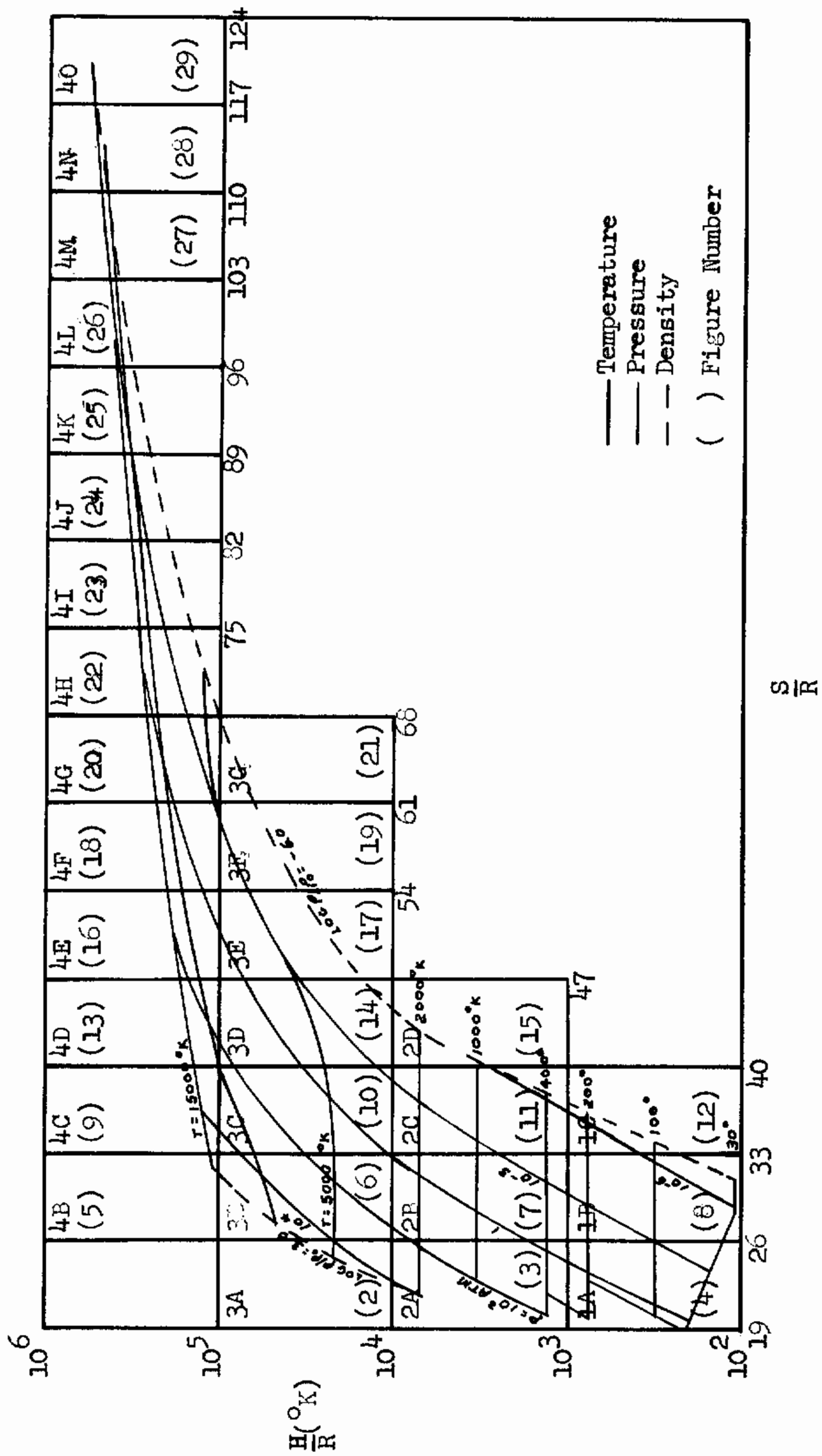
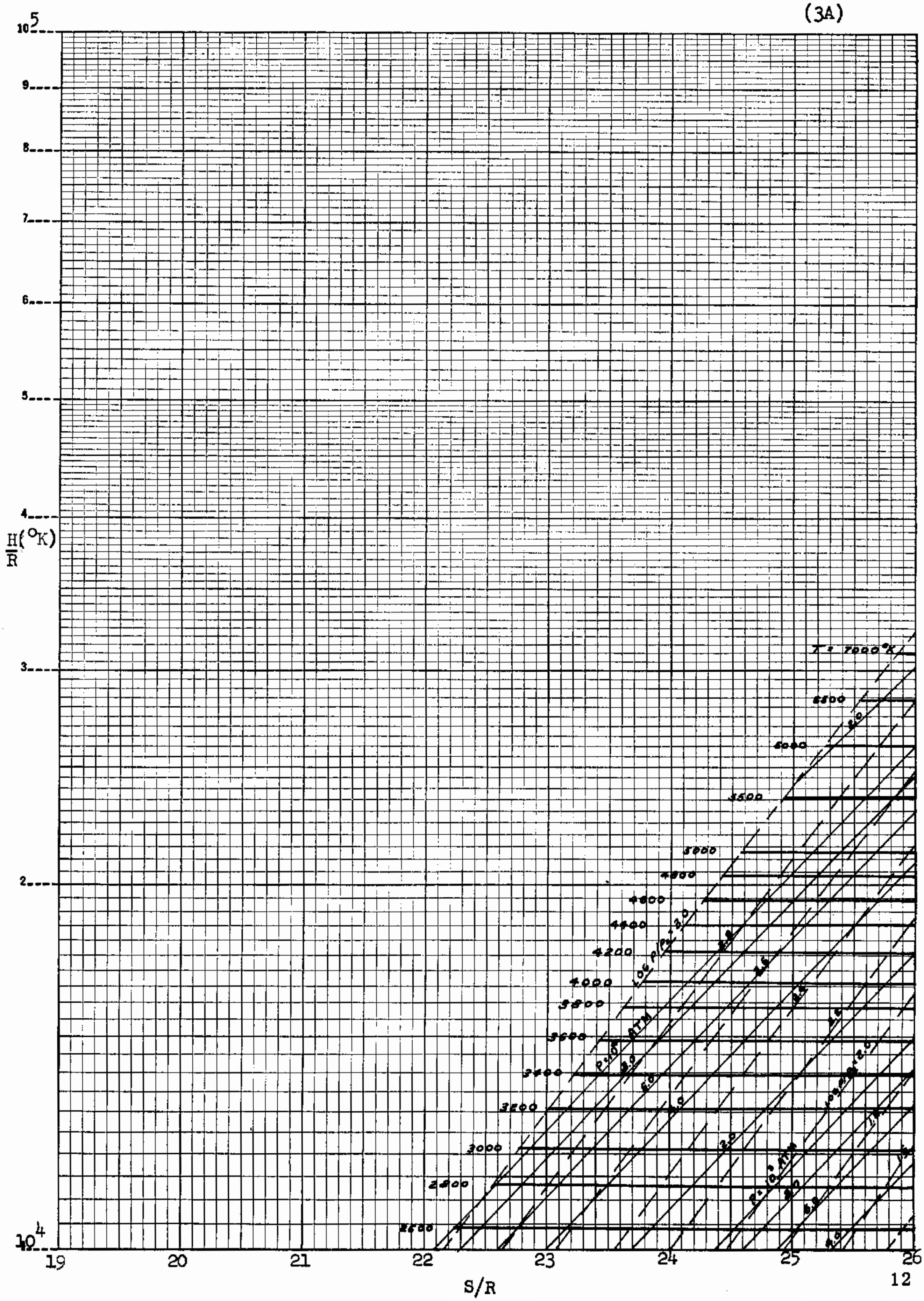


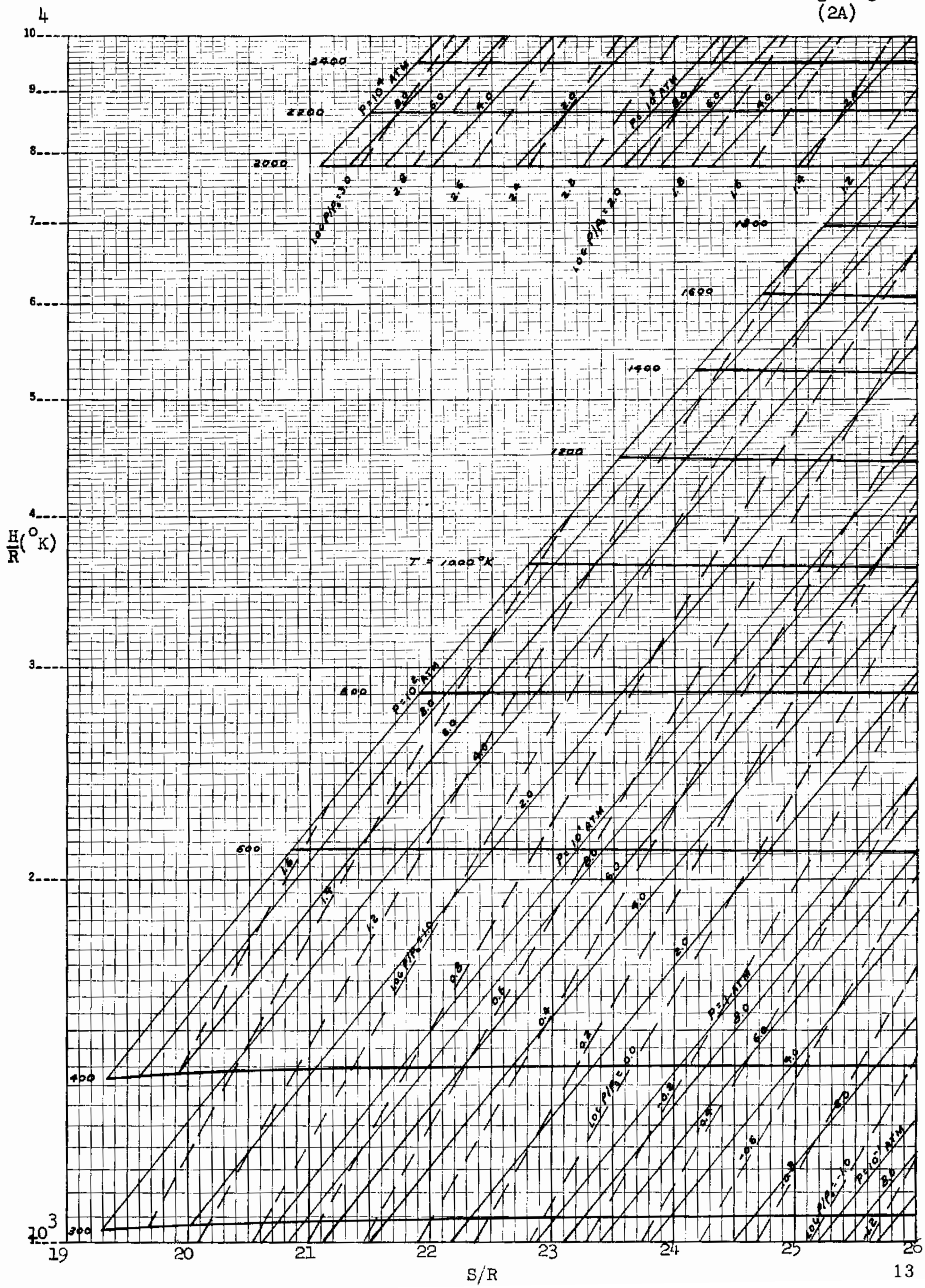
Fig. 1 Index Sheet for Nitrogen Mollier Diagram

Figure 2
(3A)



10^5
9
8
7
6
5
4
3
2
10^4
$\frac{H}{R}$(°K)
T = 7000°K
6500
6000
5500
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
19
20
21
22
23
24
25
26
S/R

Figure 3
(2A)



H/R (°K)
S/R
T = 1000°K
2400
2200
2000
1800
1600
1400
1200
800
600
400
300

Figure 4
(1A)

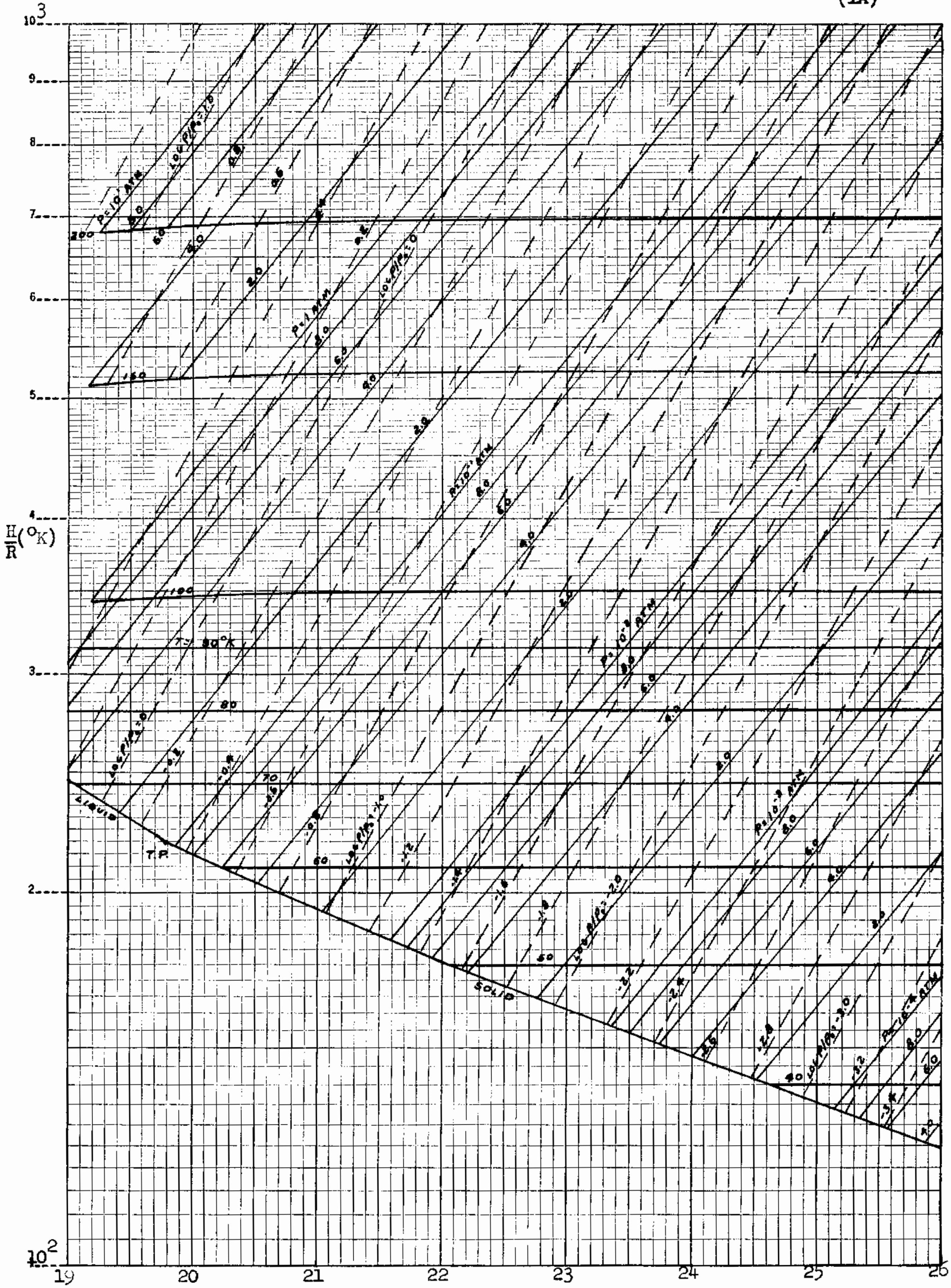

H/R (°K)
S/R
10^3
9
8
7
6
5
4
3
2
10^2
19
20
21
22
23
24
25
26
LIQUID
SOLID
T.P.
P=1 ATM
T = 90°K
200
150
100
80
70
60
50
40

Figure 5
(4B)

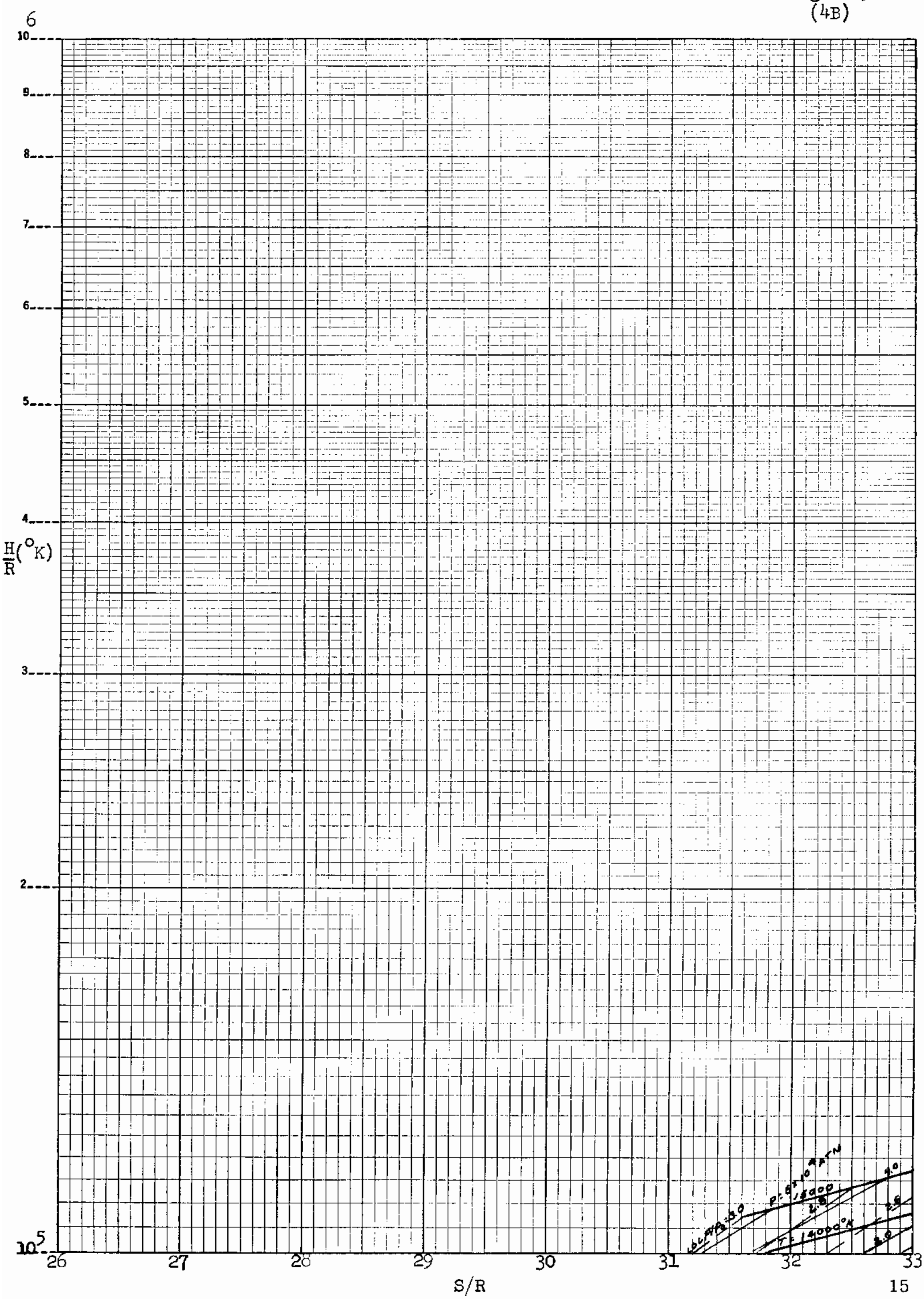

6
10
9
8
7
6
5
4
3
2
10^5
$\frac{H}{R}$(°K)
26
27
28
29
30
31
32
33
S/R
4.0
14000°K
15000

Figure 6
(3B)

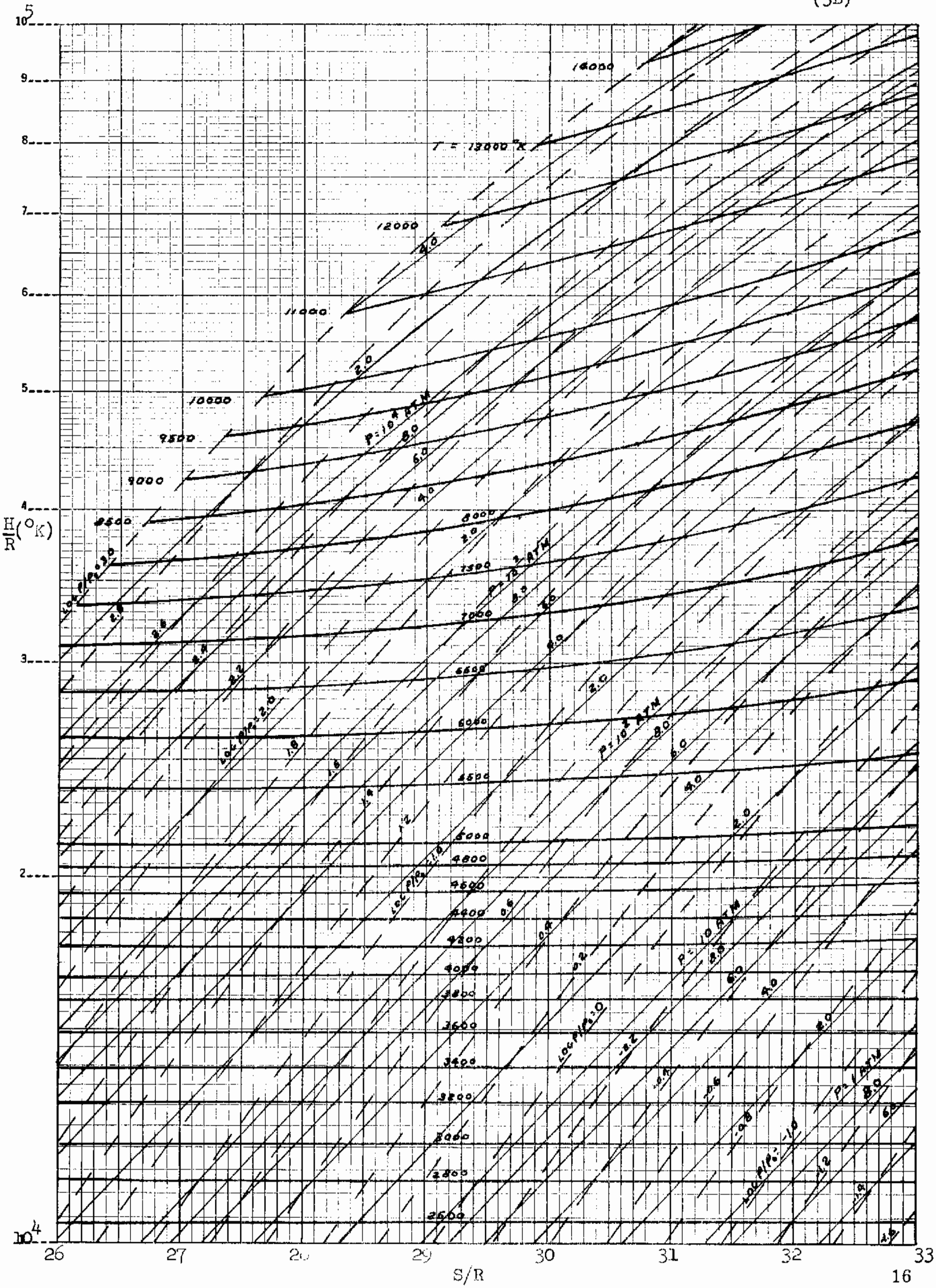
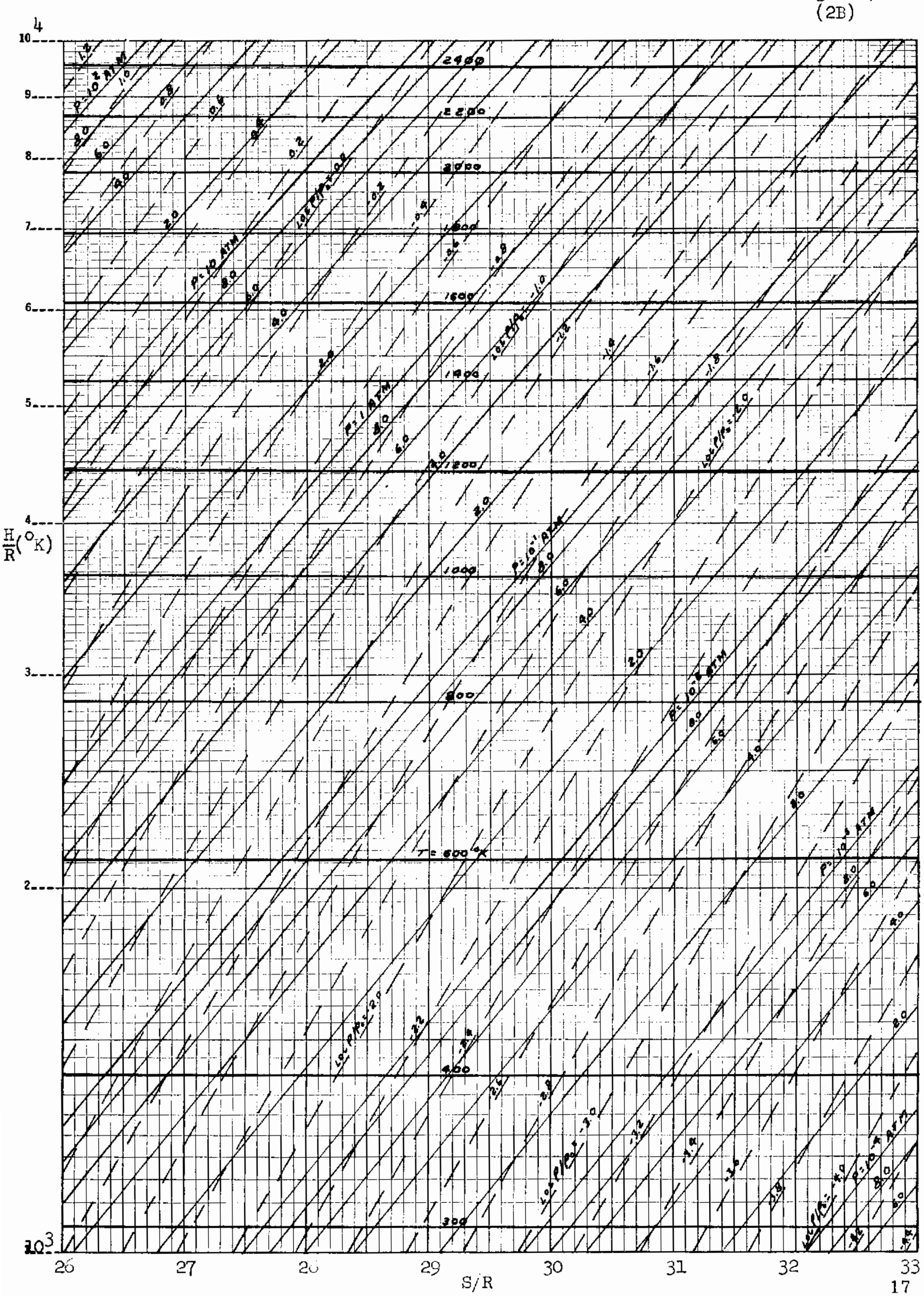

10^5
9
8
7
6
5
4
3
2
10^4
$\frac{H}{R}$ (°K)
26
27
29
30
31
32
33
S/R
T = 13000 °K
14000
12000
11000
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
P = 10⁴ ATM
P = 10³ ATM
P = 10² ATM
P = 10 ATM
P = 1 ATM
LOG P/P₀ = 3.0
LOG P/P₀ = 2.0
LOG P/P₀ = 1.0
LOG P/P₀ = 0
LOG P/P₀ = -1.0

Figure 7
(2B)



10^4
9
8
7
6
5
4
3
2
10^3
2400
2200
2000
1800
1600
1400
1200
1000
800
T = 600 °K
400
300
P = 10 ATM
P = 1 ATM
$P = 10^{-1}$ ATM
$P = 10^{-2}$ ATM
$P = 10^{-3}$ ATM
$P = 10^{-4}$ ATM
H/R (°K)
26
27
28
29
30
31
32
33
S/R

Figure 8
(1B)

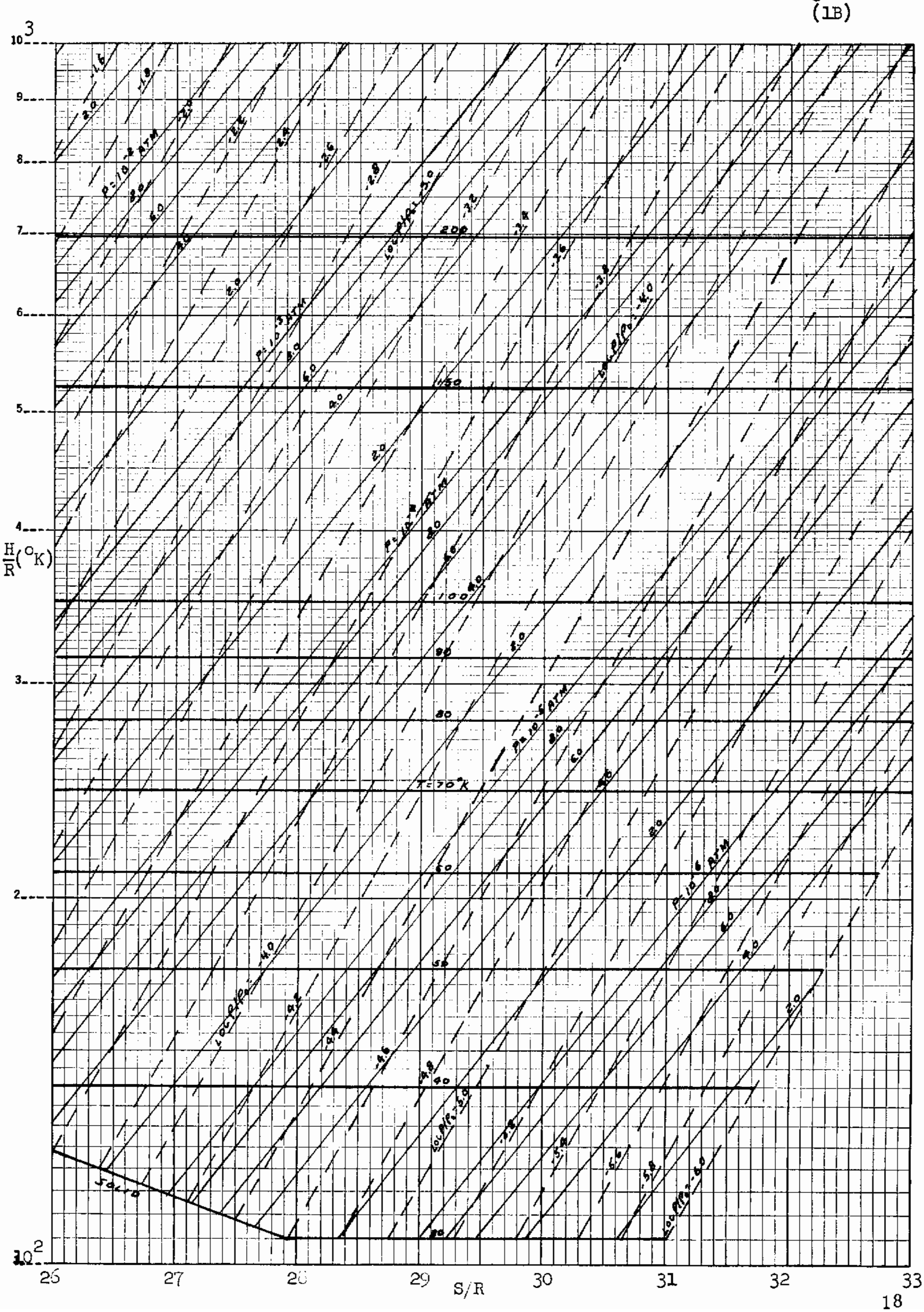


Figure 9
(4C)

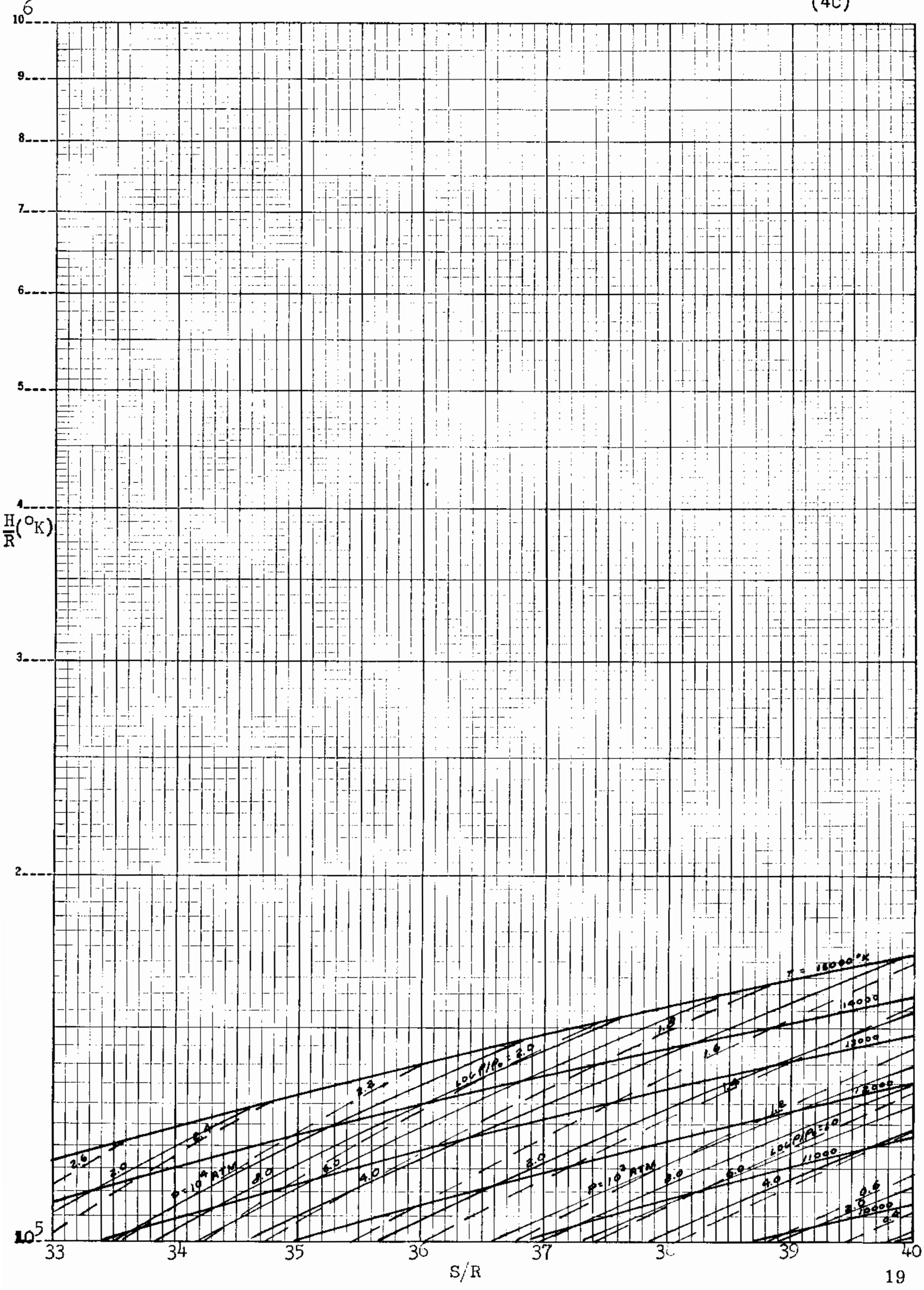

10^6
9
8
7
6
5
4
3
2
10^5
H/R (°K)
33
34
35
36
37
38
39
40
S/R
T = 15000°K
14000
13000
12000
11000
10000
P = 10^4 ATM
P = 10^3 ATM
LOG P/P₀ = 2.0
LOG P/P₀ = 1.0

Figure 10
(3C)

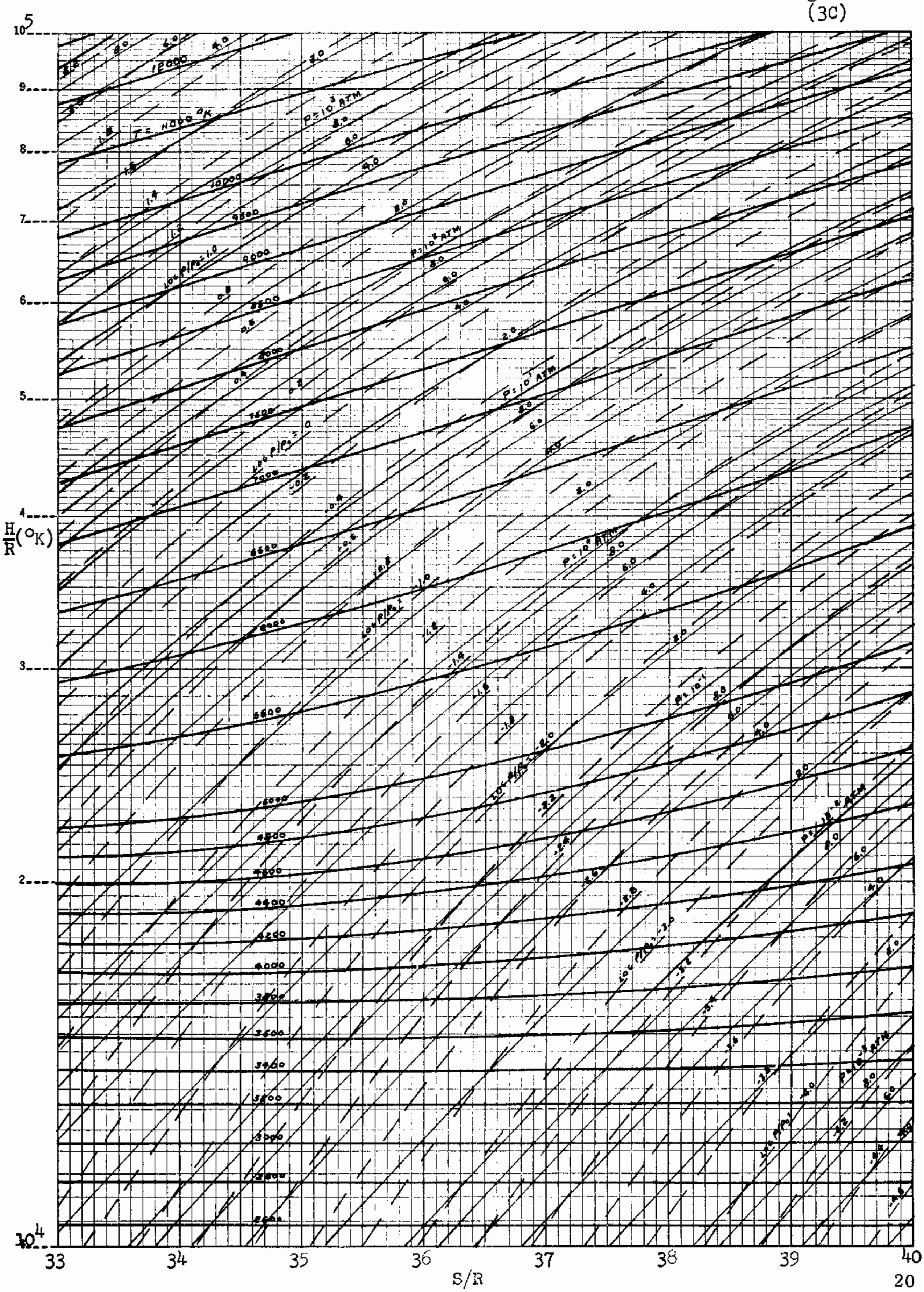

H/R (°K)
S/R
T = 11000 °K
12000
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
P=10^3 ATM
P=10^2 ATM
P=10^1 ATM
P=10^-1
P=10^-2 ATM
P=10^-3 ATM
33
34
35
36
37
38
39
40

Figure 11
(2C)

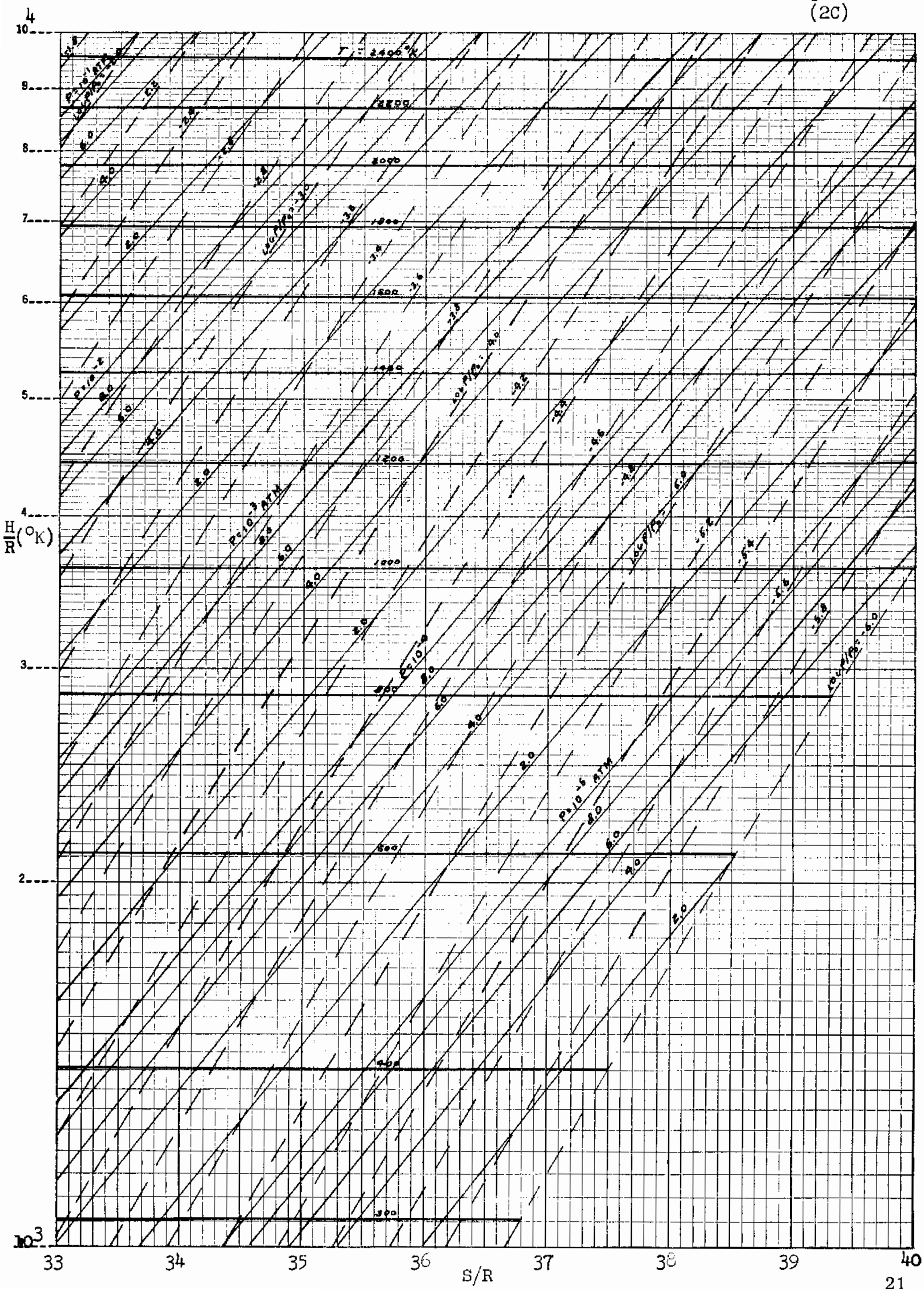

10^4
10
9
8
7
6
5
4
3
2
10^3
$\frac{H}{R}$ (°K)
T = 2400°K
2200
2000
1800
1600
1400
1200
1000
800
600
400
300
P = 10^{-3} ATM
P = 10^{-6} ATM
33
34
35
36
37
38
39
40
S/R

Figure 12
(1C)

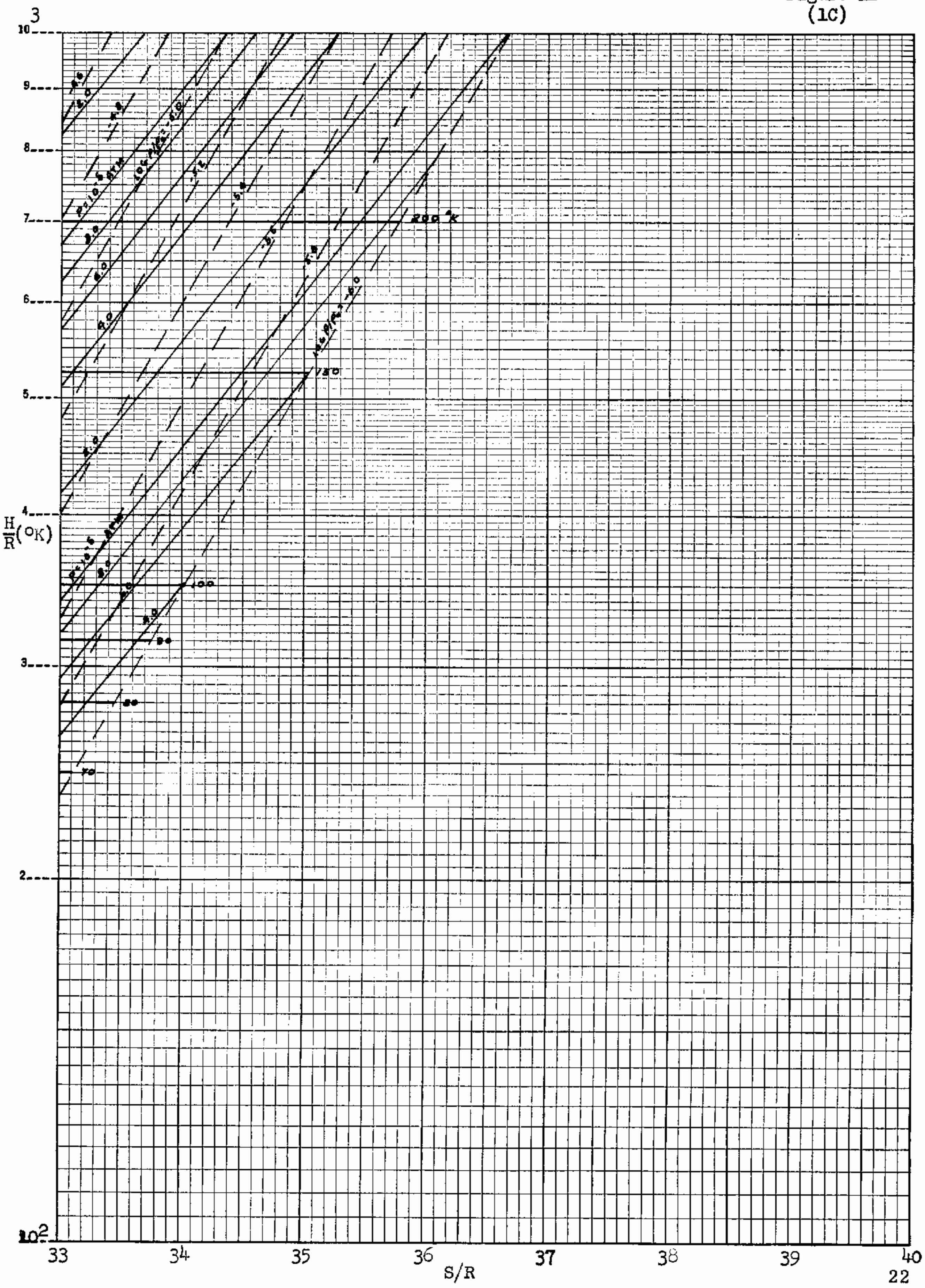
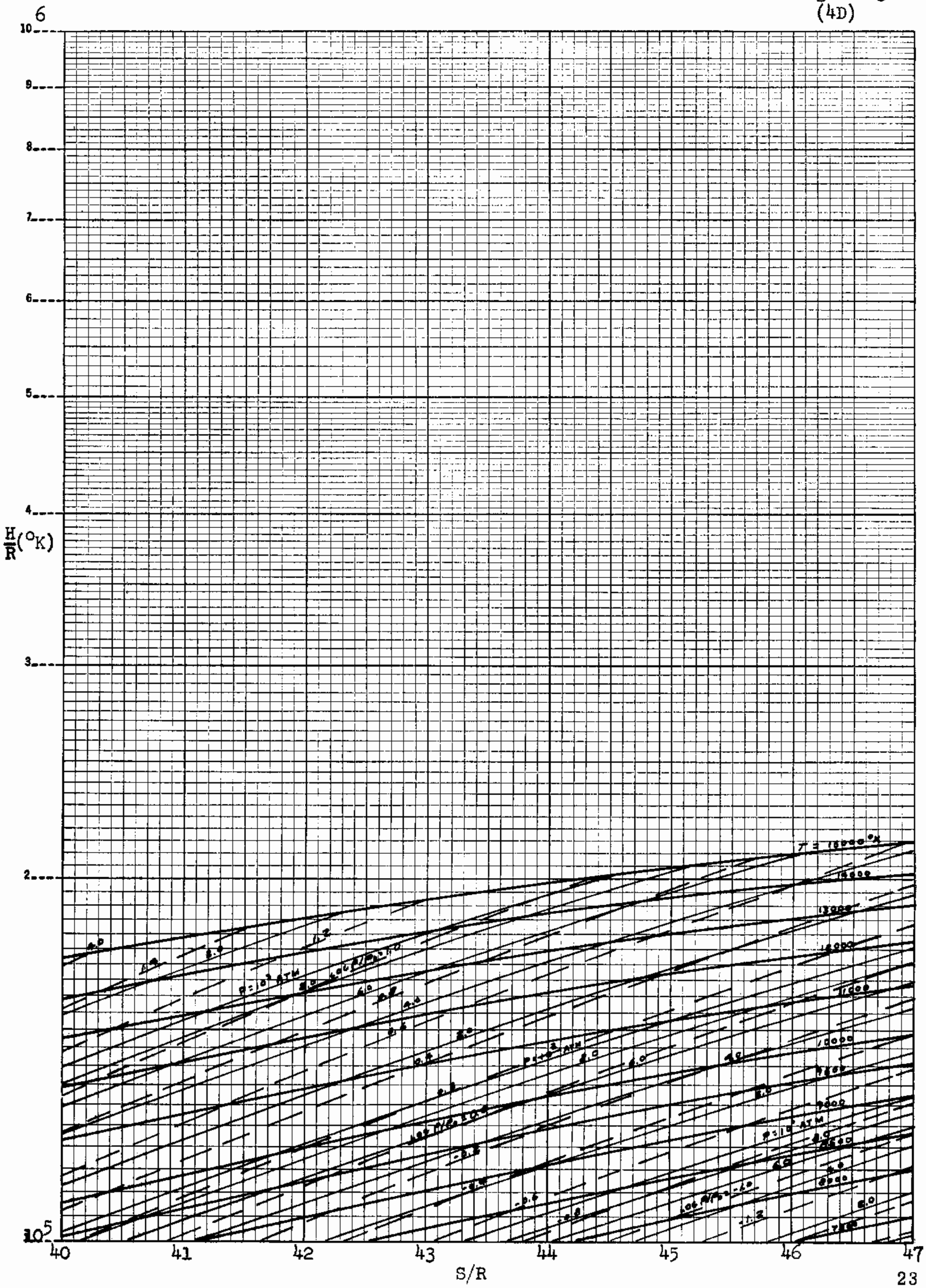


Figure 13
(4D)



10^6
10
9
8
7
6
5
4
$\frac{H}{R}$ (°K)
3
2
10^5
40
41
42
43
44
45
46
47
S/R
T = 16000 °K
14000
13000
12000
11000
10000
9000
8000

Figure 14
(3D)

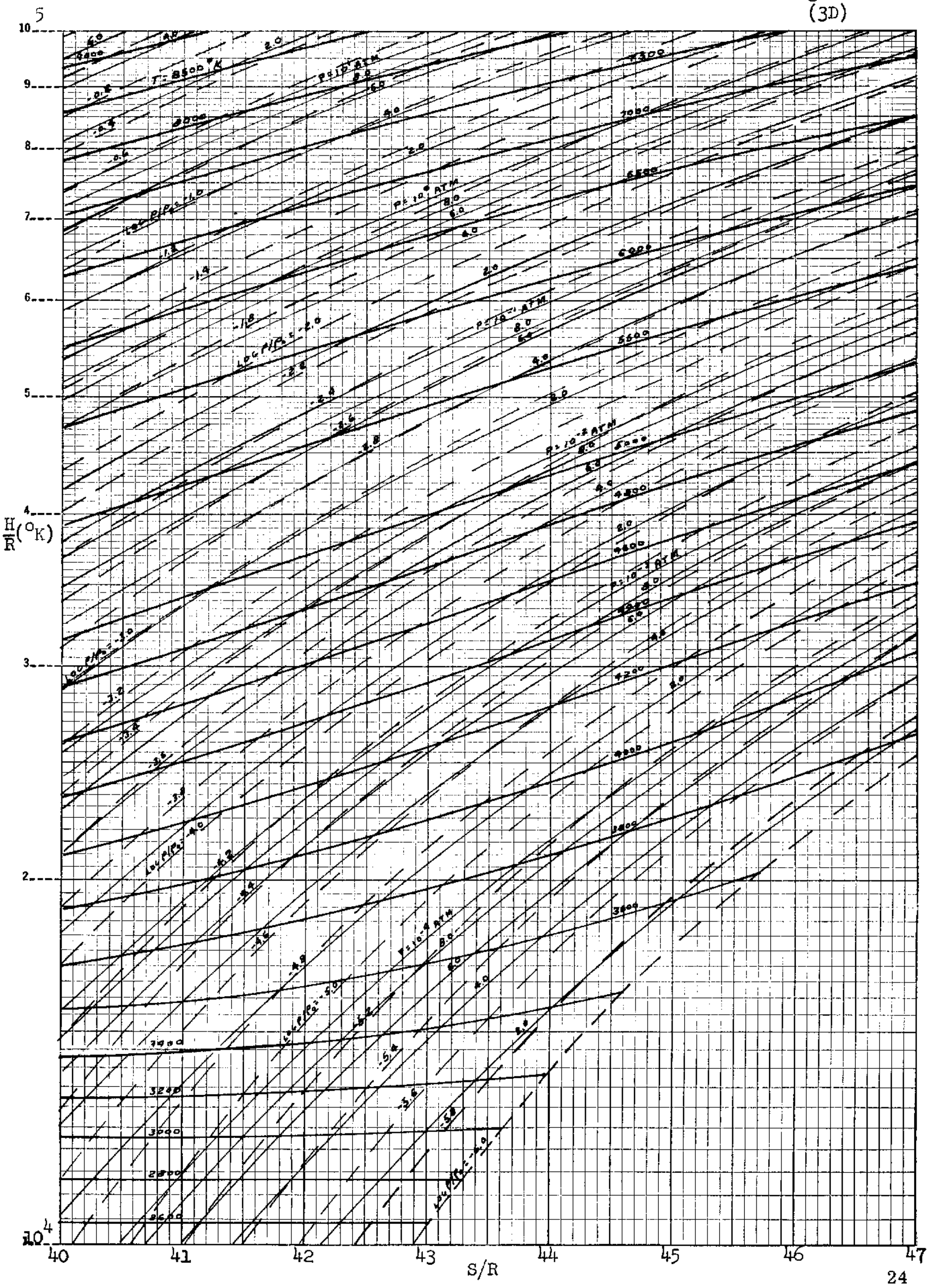

T = 8500°K
P = 10 ATM
P = 10^-1 ATM
P = 10^-2 ATM
P = 10^-3 ATM
P = 10^-4 ATM
LOG P/P₀ = 1.0
LOG P/P₀ = -2.0
LOG P/P₀ = -3.0
LOG P/P₀ = -4.0
LOG P/P₀ = -5.0
LOG P/P₀ = -6.0
7500
7000
6500
6000
5500
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
H/R (°K)
S/R
40
41
42
43
44
45
46
47

Figure 15
(2D)

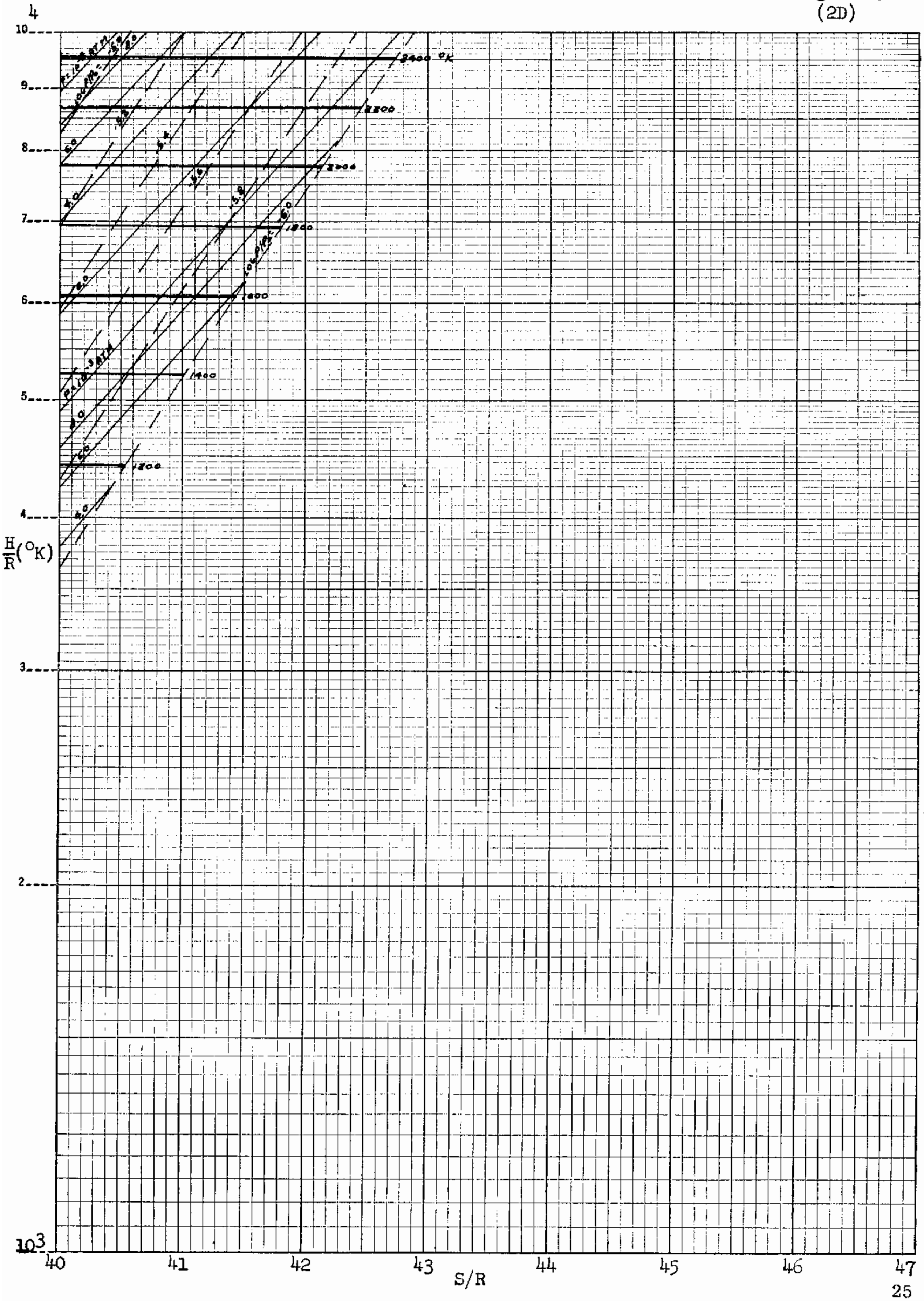


Figure 16
(4E)

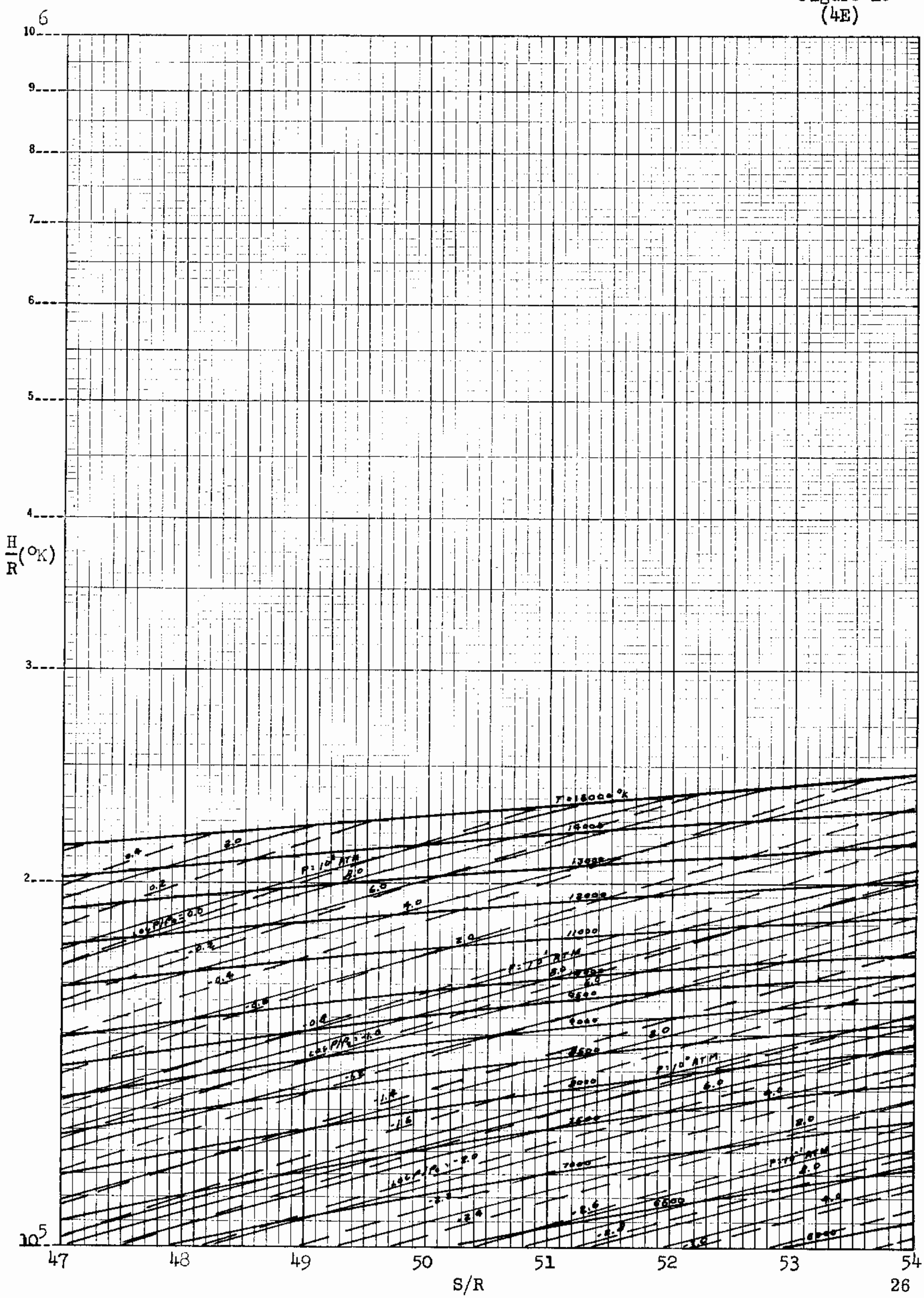

10^6
9
8
7
6
5
4
H/R (°K)
3
2
10^5
47
48
49
50
51
52
53
54
S/R
T = 15000 °K
14000
13000
12000
11000
2000
3000
P = 10^2 ATM
P = 10^1 ATM
P = 10^0 ATM
P = 10^-1 ATM
6.0
4.0
2.0
8.0
Log P/P0 = 0.0
Log P/P0 = -1.0
Log P/P0 = -2.0
-1.4
-1.6
7000
6600

Figure 17
(3E)

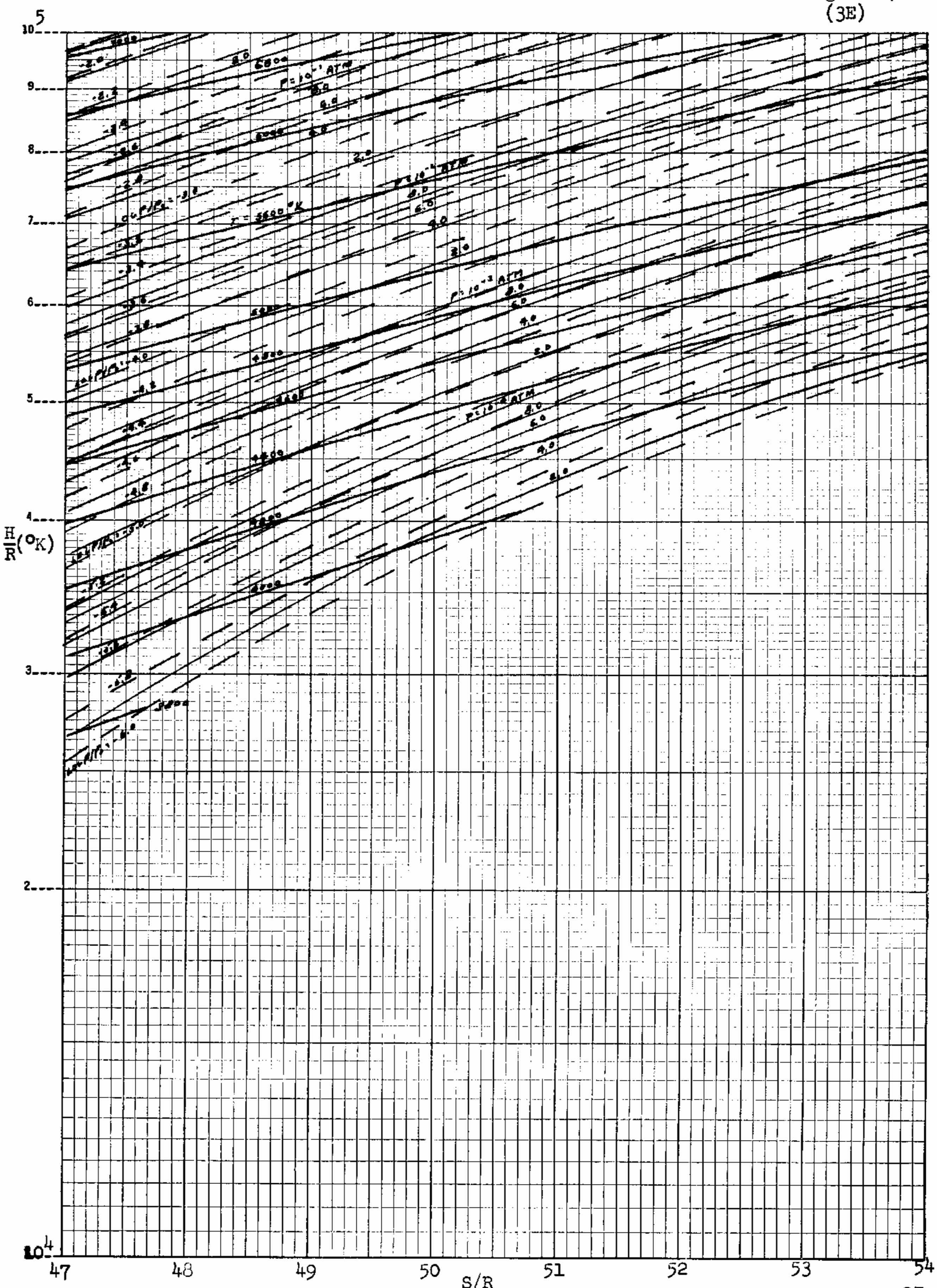
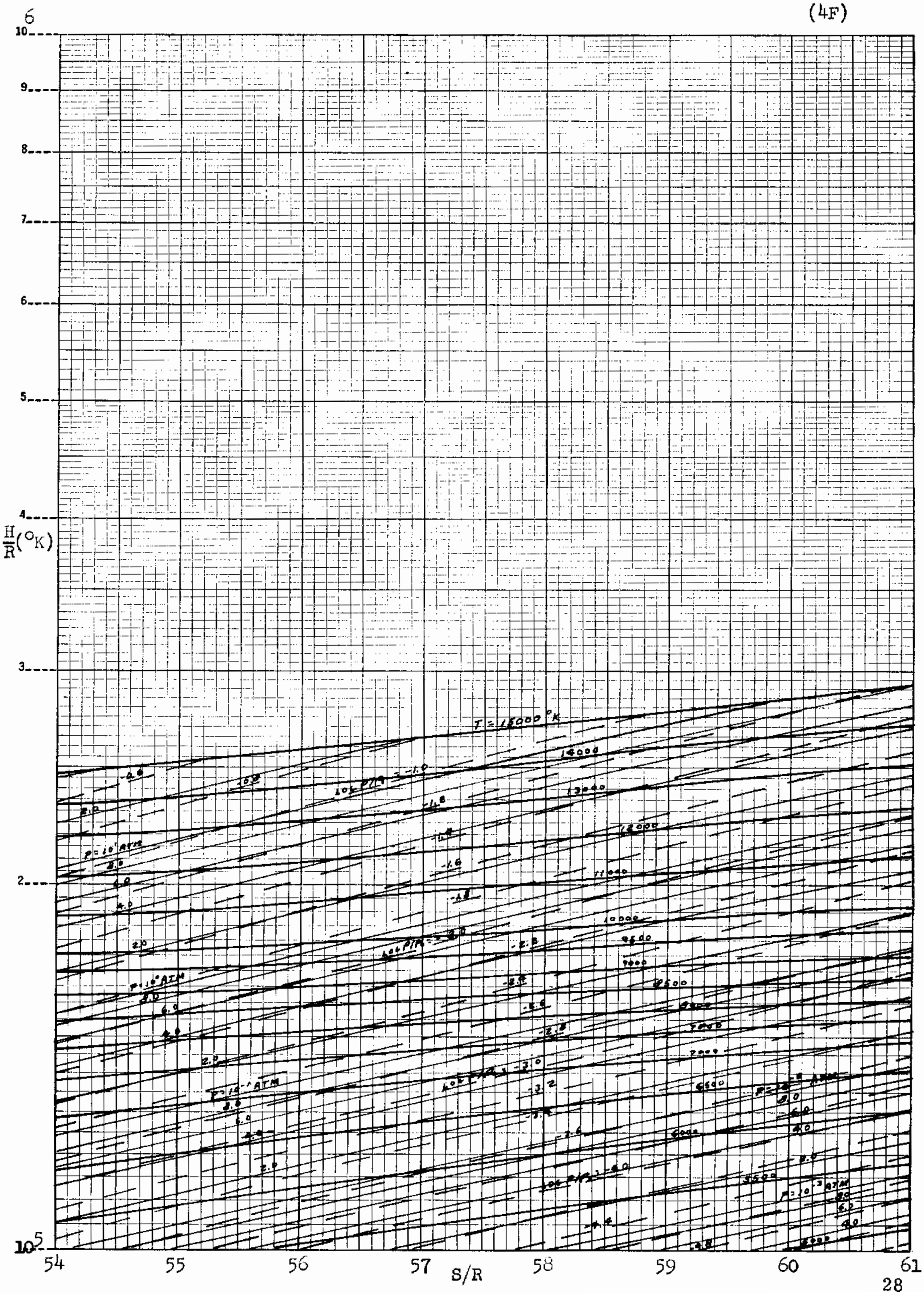


Figure 18
(4F)



H/R (°K)
S/R
T = 15000 °K
14000
13000
12000
11000
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
P = 10 ATM
P = 10[-1] ATM
P = 10[-2] ATM
P = 10[-3] ATM
log P/P₀ = -1.0
log P/P₀ = -2.0
log P/P₀ = -3.0
log P/P₀ = -4.0

Figure 19
(3F)

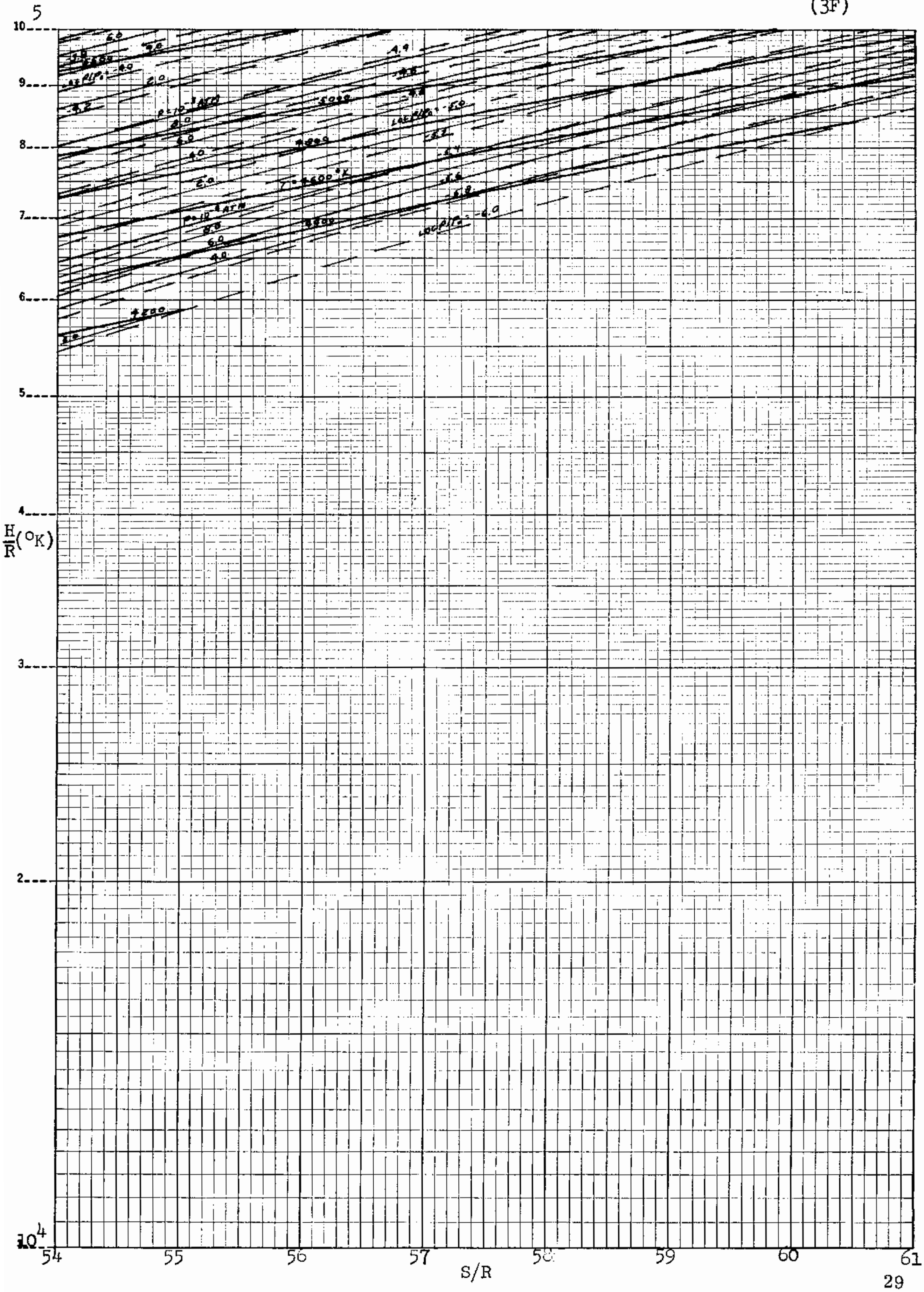


Figure 20
(4G)

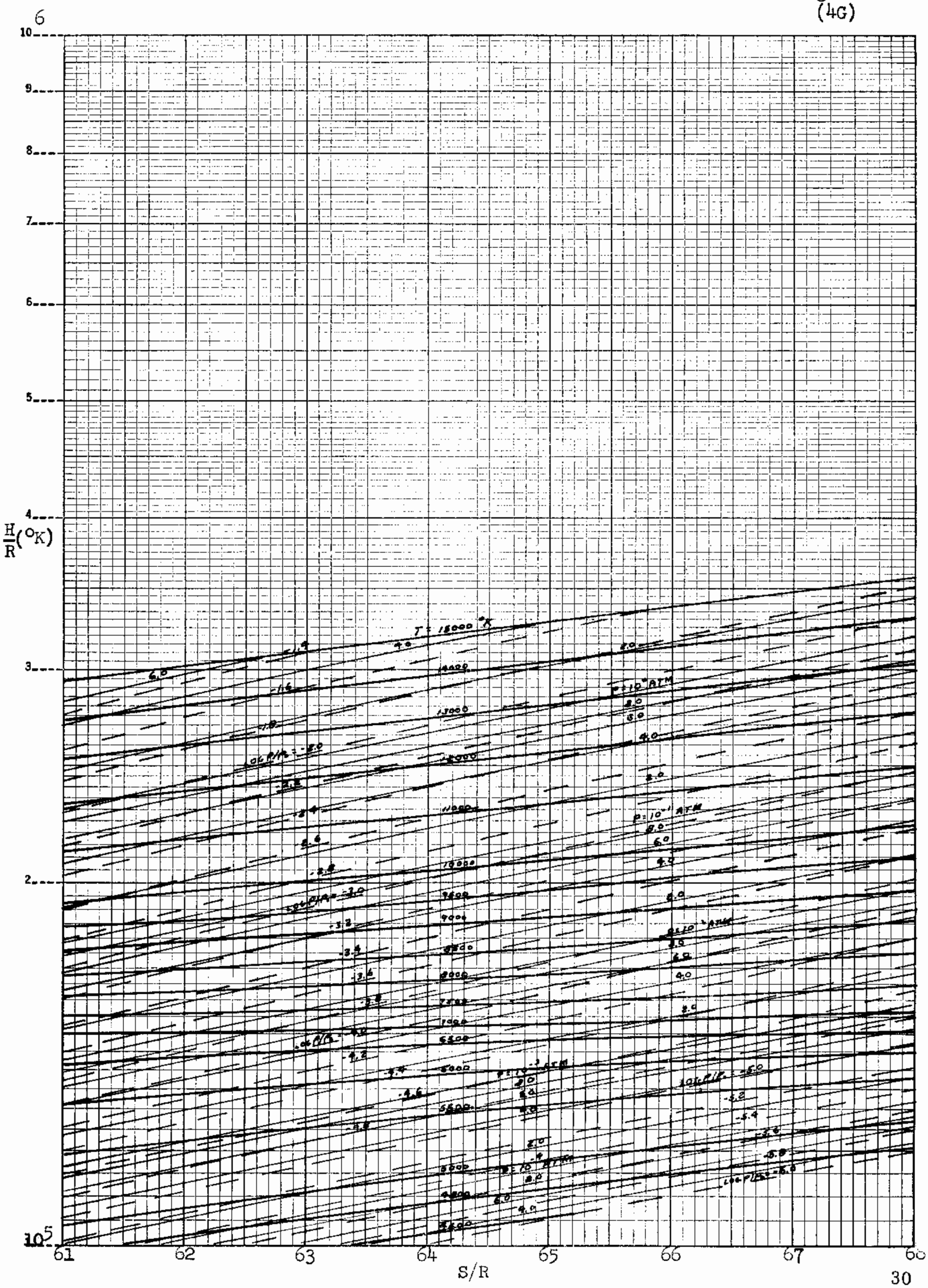


Figure 21
(3G)

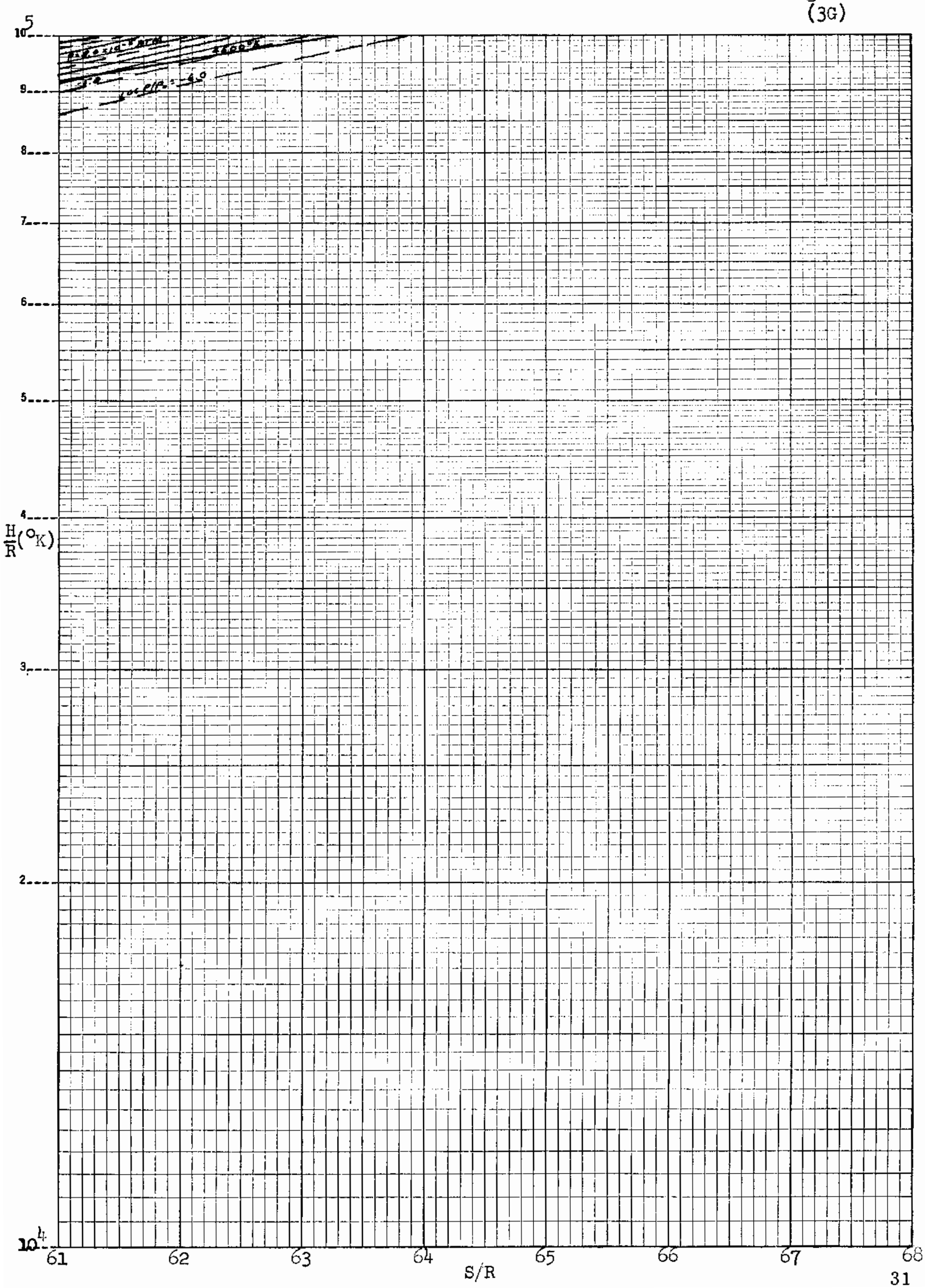


Figure 22
(4H)

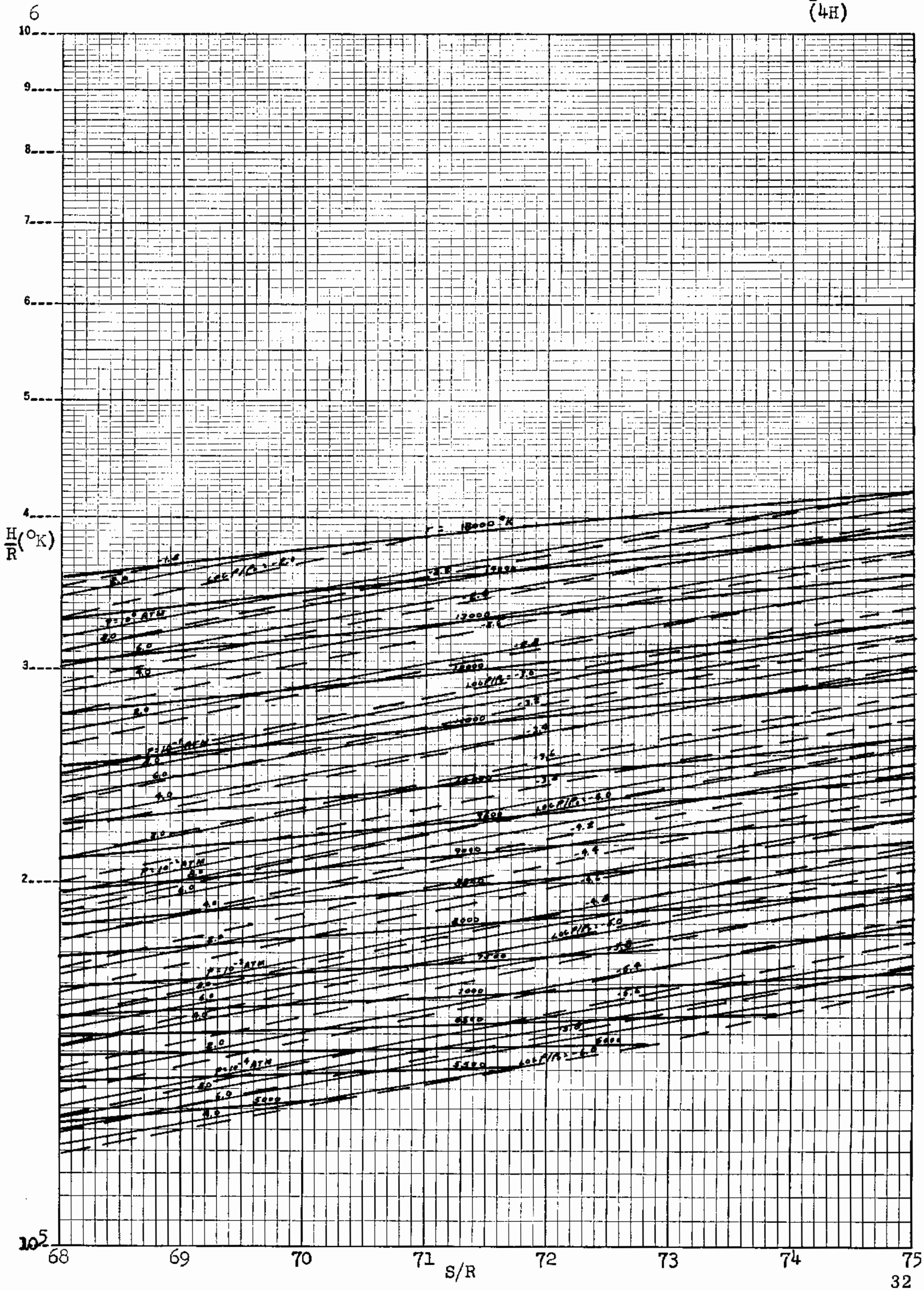


Figure 23
(4I)

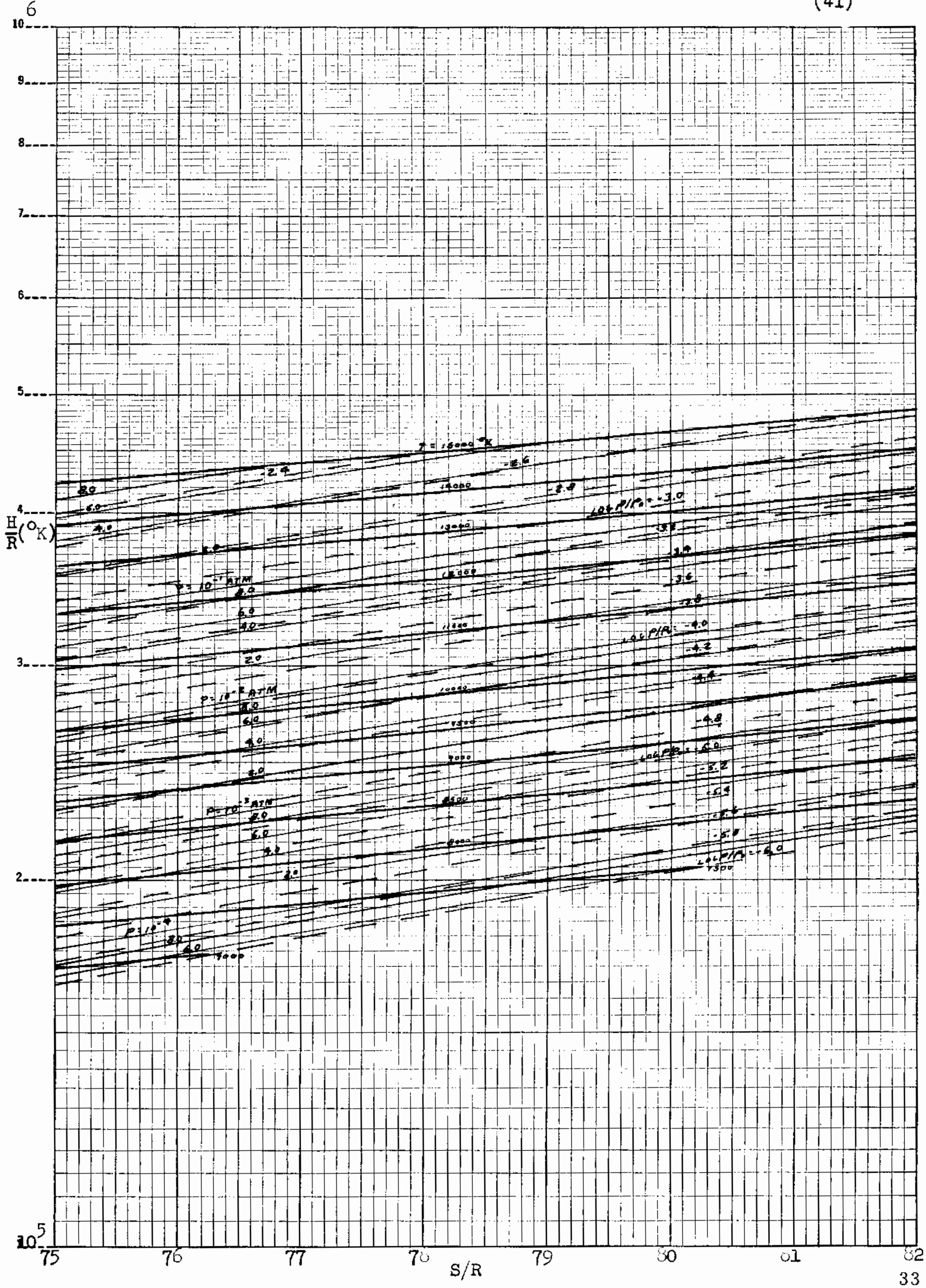
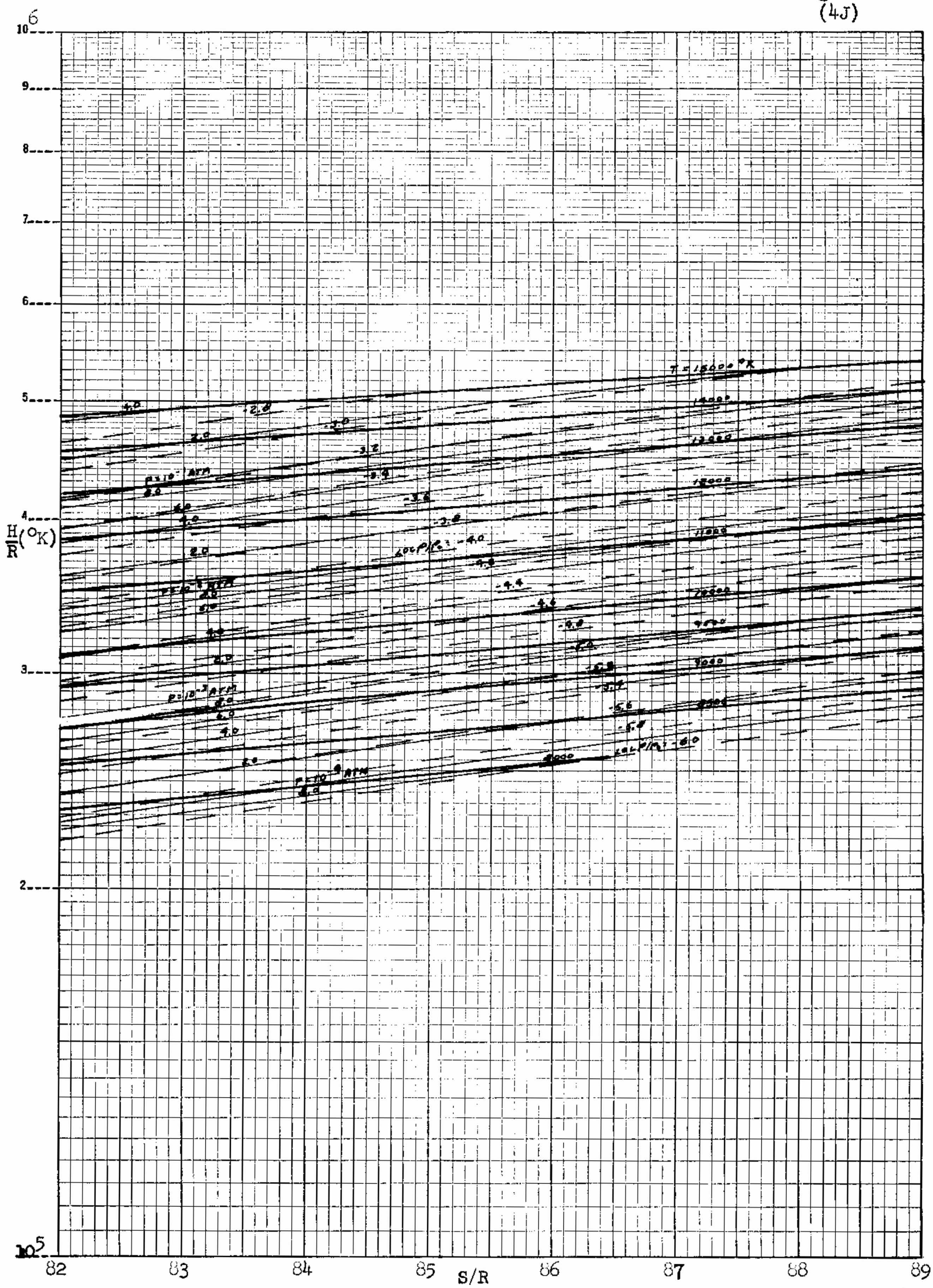

10^6
10
9
8
7
6
5
4
3
2
10^5
H/R (°K)
75
76
77
78
79
80
81
82
S/R
P = 10^{-1} ATM
P = 10^{-2} ATM
P = 10^{-3} ATM
P = 10^{-4}
T = 15000 °K
14000
13000
12000
11000
10000
9500
9000
8500
8000
7500
7000
LOG P/P₀ = -3.0
LOG P/P₀ = -4.0
LOG P/P₀ = -5.0
LOG P/P₀ = -6.0

Figure 24
(4J)



10^6
9
8
7
6
5
4
3
2
10^5
$\frac{H}{R}$ (°K)
82
83
84
85
86
87
88
89
S/R
T = 15000 °K
14000
13000
12000
11000
10000
9500
9000
8500
8000

Figure 25
(4K)

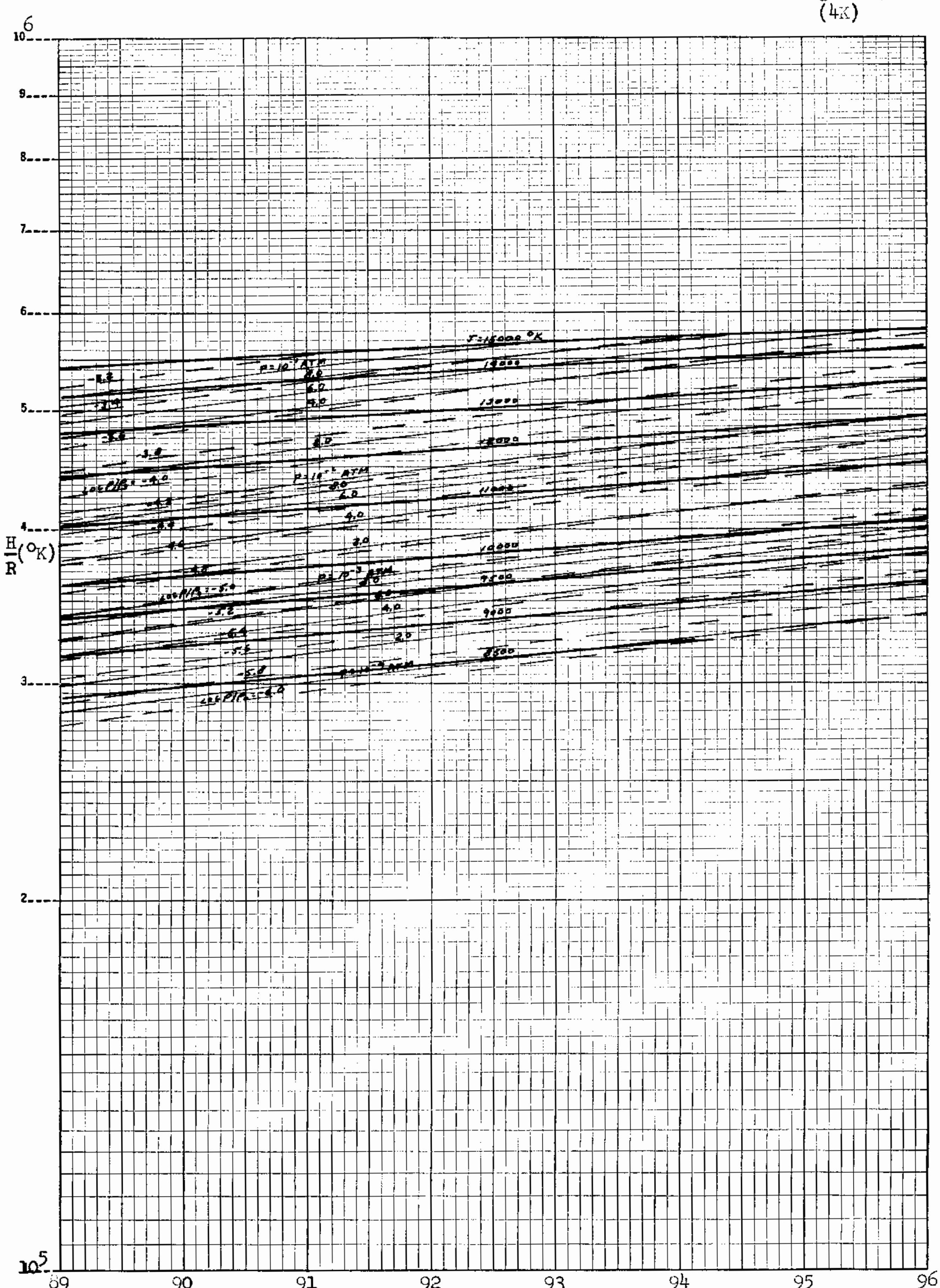

H/R (°K)
S/R
10^6
9
8
7
6
5
4
3
2
10^5
89
90
91
92
93
94
95
96
T=15000 °K
14000
13000
12000
11000
10000
9500
9000
8500

Figure 26
(4L)

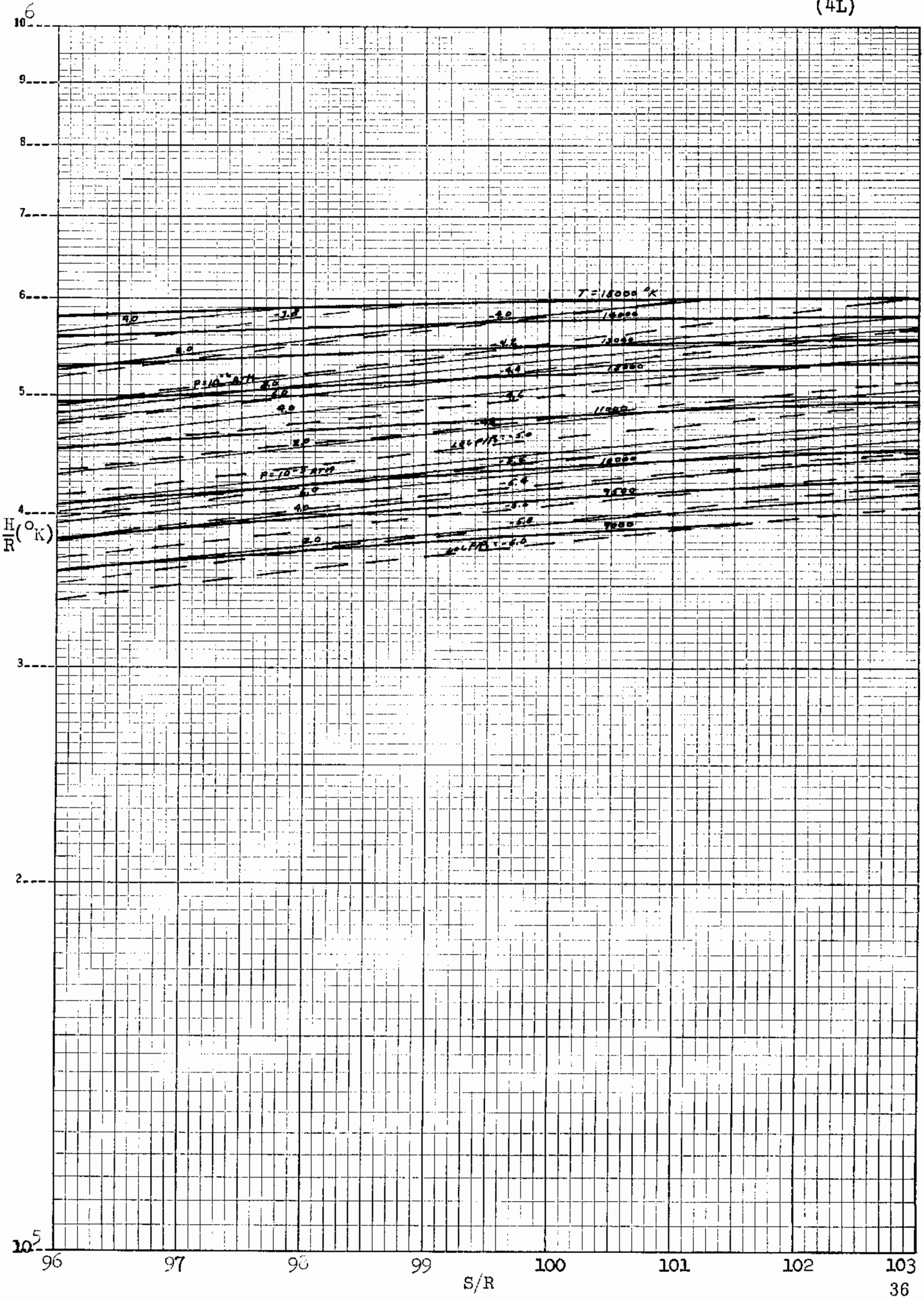


Figure 27
(4M)

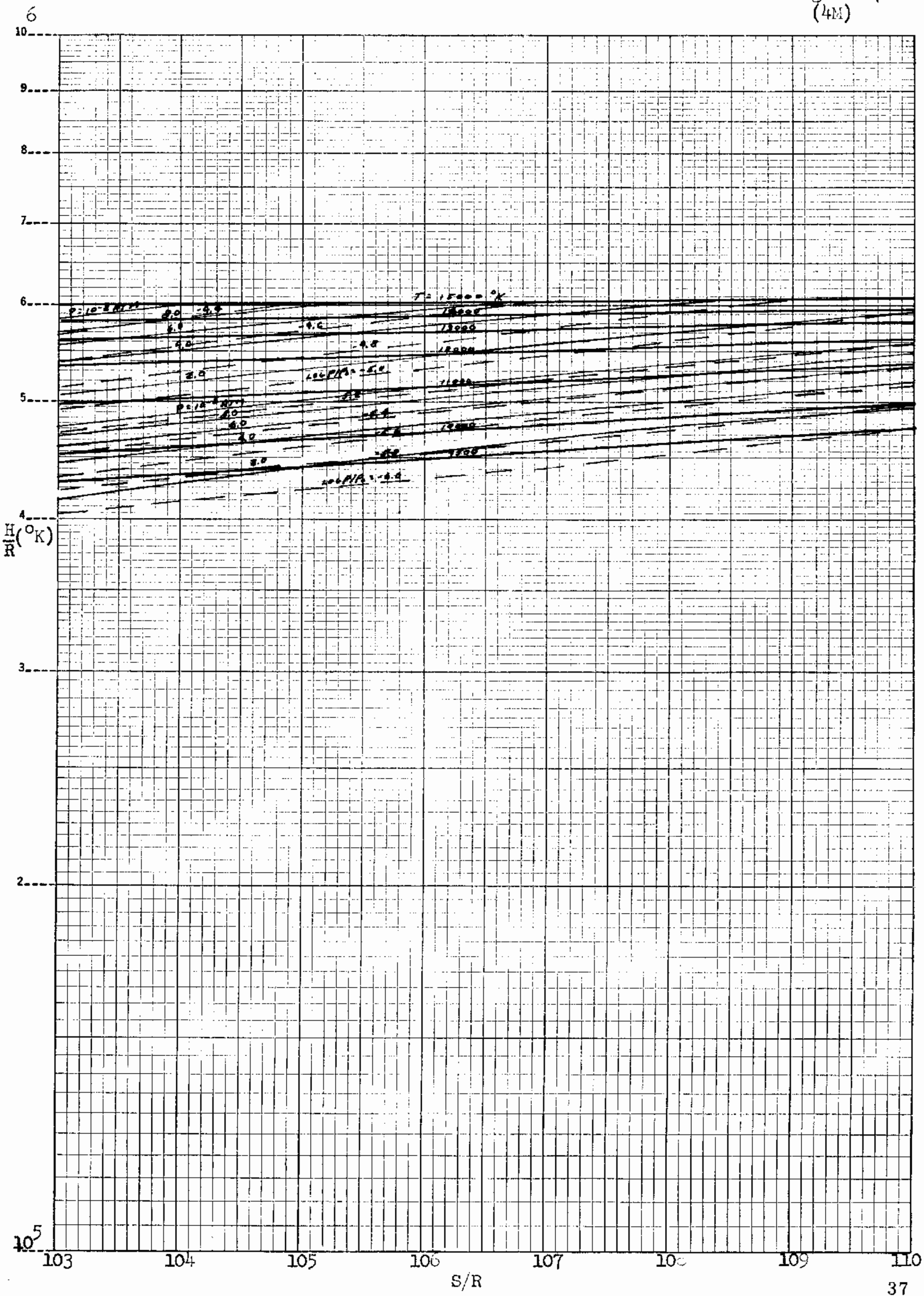

6
10
9
8
7
6
5
4
3
2
10^5
$\frac{H}{R}$(°K)
103
104
105
106
107
108
109
110
S/R
13000
12000
11000

Figure 28
(4N)

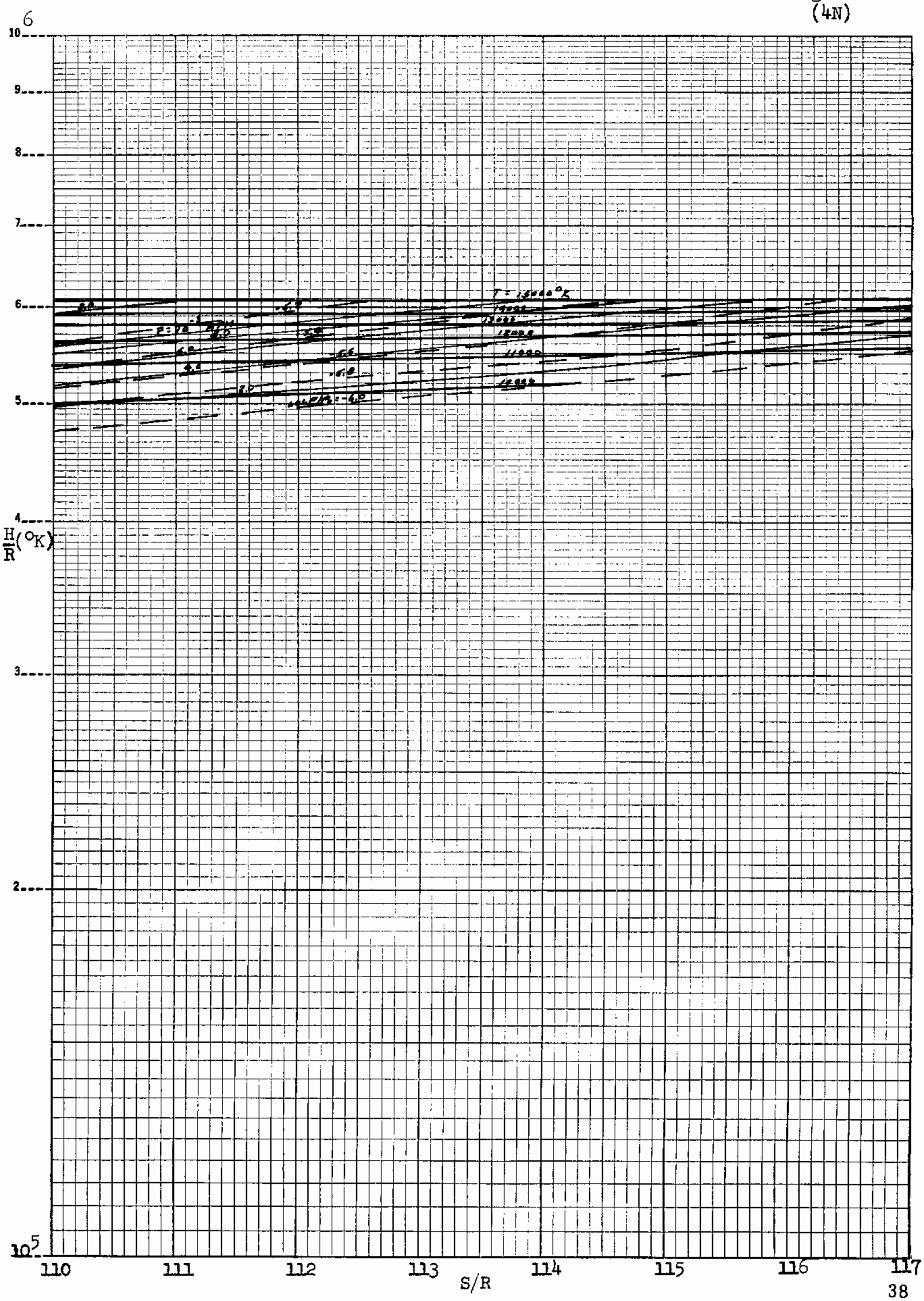
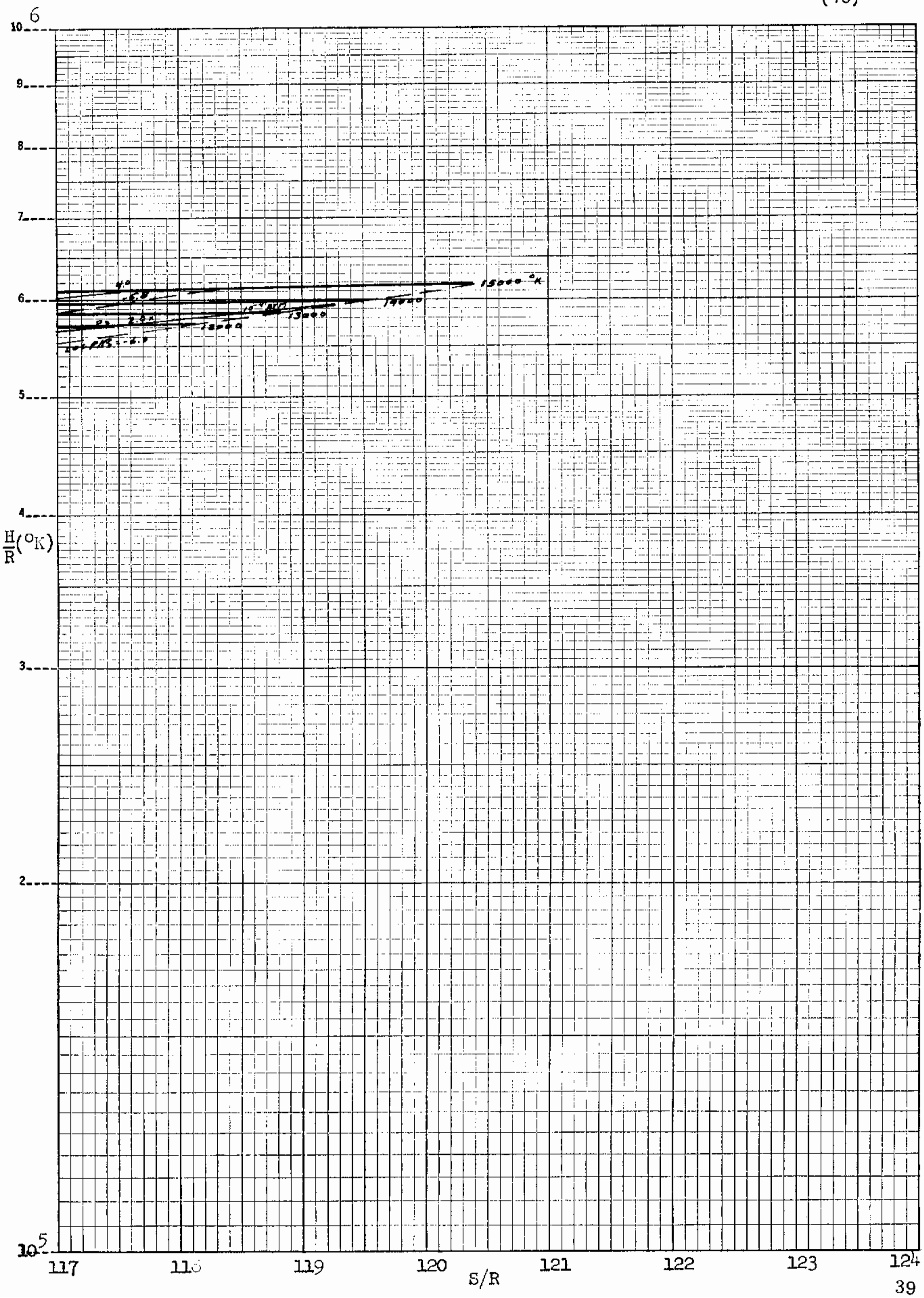

10^6
9
8
7
6
5
4
3
2
10^5
$\frac{H}{R}$ (°K)
110
111
112
113
114
115
116
117
S/R
T = 15000 °K
14000
13000
12000
11000
10000

Figure 29
(40)



15000 °K
14000
13000
12000
10^6
9
8
7
6
5
4
$\frac{H}{R}$(°K)
3
2
10^5
117
118
119
120
121
122
123
124
S/R