CERTIFICATE

This is to certify that Ms. VRINDA N has satisfactorily completed the project entitled Measurement of Optical Depth of the Atmosphere using the 1.5 m Radio Telescope at the millimetre wave department, Raman Research Institute, Bangalore, during the year 1985 - 1986. The work has been sponsored by the Indian Physics Association (Bangalore Chapter)

Measurement of Optical Depth of the Atmosphere Using the 1.5m Radio Telescope at R.R.I

by

VRINDA. N.

ACKNOWLEDGEMENT

My sincere thanks to Dr. Arora , but for whose encouragement and enormous patience this project would not have been a success.

I also thank Mr. Nimesh who made all concepts seem very simple and Mr. Sukumar who introduced me to computers.

Vrinda. R.
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ABSTRACT

Presented in this report is the work done in connection with a project to measure the optical depth of the atmosphere at 110 GHz using the 1.5 m radio telescope at the Raman Research Institute, Bangalore.

The radio telescope has been briefly described in the first chapter. The theoretical and experimental determination of optical depth has been dealt with in the second chapter. The results of observations done on various days have been presented along with the analysis procedure. The zenith optical depth of the atmosphere was found to be between 0.1 and 0.3 during the months of December'85 and January '86.

CHAPTER 1

THE RADIO TELESCOPE

1.1 INTRODUCTION

Radiation from outer space should penetrate the earth's atmosphere to be observed at the ground level. Not all radiation reaches the earths' surface. The atmosphere is opaque over most of the electromagnetic spectrum except in two regions referred to as " windows ". The first window occurs in the visible region from 4000 A° to 8000 A° and the second in the radio wave region from 10^{-2} m to 10 m as shown in Fig. 1.1 This limit has been set due to the reflection of the longer wave length by the ionosphere and absorption of the shorter wavelength in the atmospheric gases. However, the radiation can be received through some narrow "windows" at millimeter and infrared wavelengths where the absorption due to atmospheric gases is small.

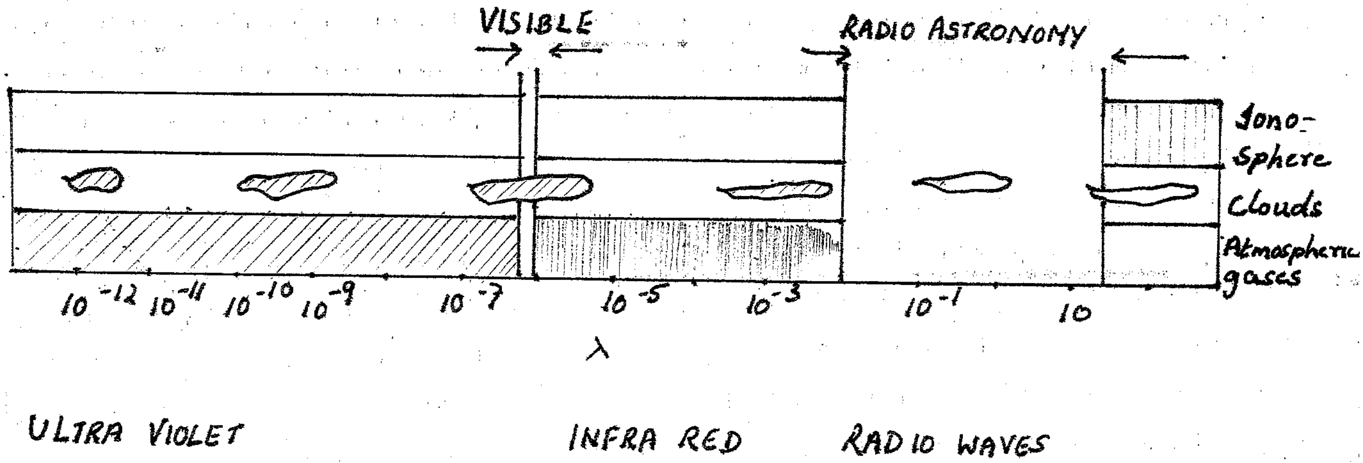


Fig. 1.1 Opacity of the atmosphere over the electromagnetic spectrum

Both light and radio waves are electro-magnetic waves differing only in their wavelength, origin and propagation. Cosmic Radio waves are generated by relativistic electron spiralling in high interstellar magnetic fields by a mechanism called synchrotron radiation. In addition, thermal emission of radio and light waves from matter occur according to classical concepts. For both radio and visible waves, Planck's black body formula can be applied.

$$E_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{\{\exp(hc/k\lambda T)-1\}} \qquad (1.11)$$

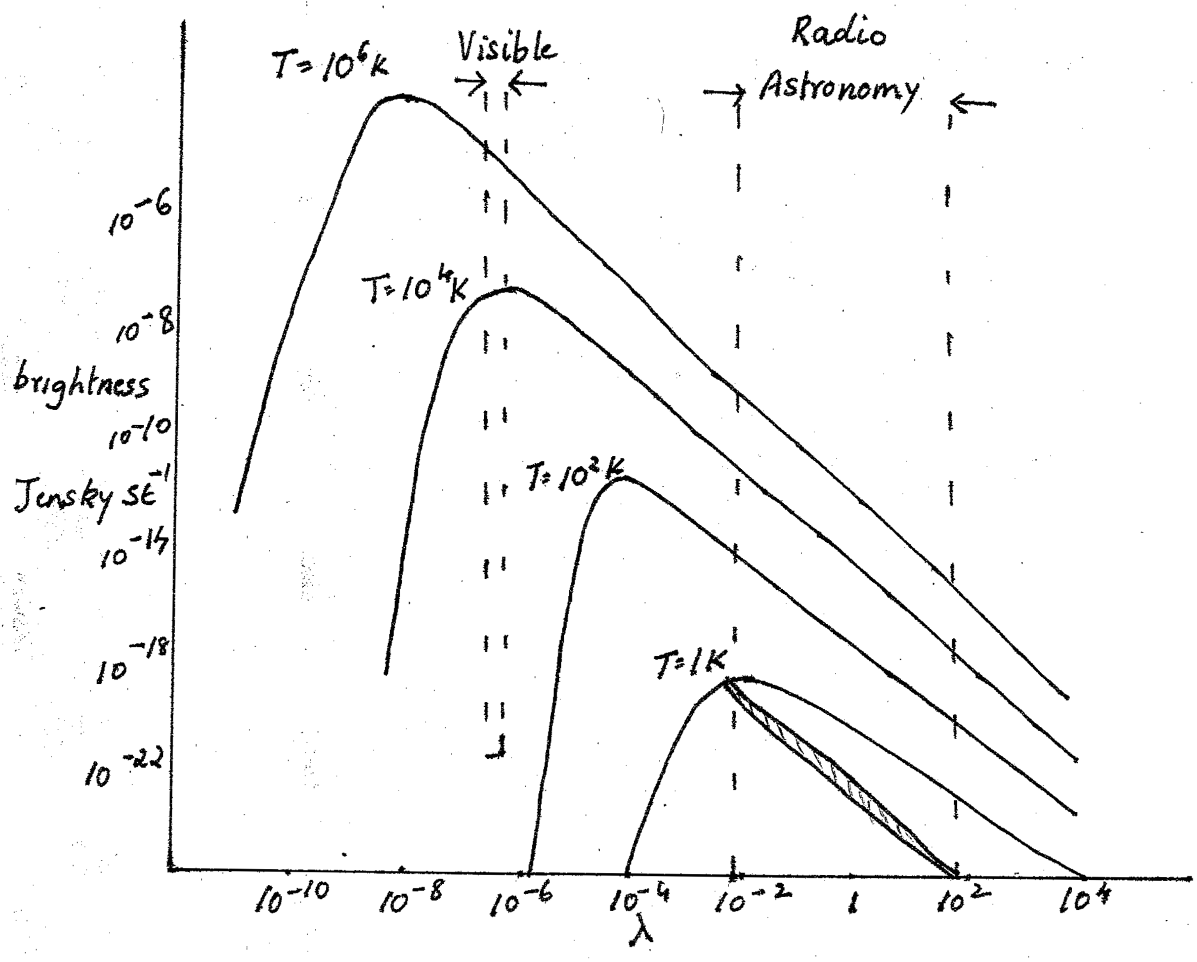


Fig 1.2:

However, the radio frequency region occurs at the straight portion to the right of the maxima of each curve in Fig. 1.2 where the Rayleigh Jeans approximation applies

$$E_f = 2kT/\lambda^2 \qquad (1.12)$$

From the graph we notice that :

1) Only bodies at higher temperature emit visible rays
2) The intensity of light waves emitted is greater than radio waves for hot bodies and vice versa for cold bodies.

The most notable difference is the ability of radiowaves to penetrate clouds because of their wavelength which is greater than the cloud particle size. The radio telescope can receive signals from greater distances than the optical telescope on the earths' surface. However, the resolution of optical telescopes was better because of such shorter wavelength of light. To improve the resolution at radio wavelengths, interferometric methods were developed and now a days resolution of the order of milli arc seconds is obtained using VLBI (Very long Baseline Interferometry) which is several orders of magnitude better than those obtained with the best optical telescopes.

A radio telescope in its simplest form consists of three parts:

i) the antenna that selectively collects radiation from a small region of the sky
ii) a radiometric receiver, referred to as a radiometer that amplifies a restricted frequency band from the

output of the antenna and

iii) a computer that registers and records the radiometer output.

1.2 Antenna

The antenna is a reflector usually paraboloid in shape. The geometrical property of the parabola ensures all waves falling on it to be brought to focus at a point. Every antenna has the following general characteristics.

a) Input Impedence: The impedance appearing at its input termin~~als when~~ it is coupled to a transmitter

b) Polarisation: The sense of polarisation that it receives or radiates in every direction. This may be linear, circular or elliptical.

c) Radiation pattern: Radiation pattern is a plot of the antenna radiated power as a function of direction (~~Refer. Fig. 1.3~~) A good directional antenna radiates most of its energy in one direction with the angular width or beam width determined by the size of the antenna and the wavelength of radiation. Weaker secondary maxima in other directions are called side lobes.

d) Gain or directivity: The radiated power in the direction of the main beam relative to what would be radiated by an isotropic antenna in that direction.

e) Effective collecting area A_e : It is the ratio of the power W in the terminating impedence to the flux P of the incident wave.

$$A_e = W / P \qquad (1.21)$$

A good directional antenna is one which has a smaller beam width. The beam width

$$\theta = \lambda / D \qquad (1.22)$$

where λ is the wavelength of the incident wave and D the diameter of the antenna. Thus increasing the diameter would decrease the beamwidth. However, building a very large steerable antenna without any surface irregularities presents an engineering problem.

One of the antenna at the Raman Research Institute has a diameter of 1.5 m. The azimuth elevation mounting or 'az-el' mounting enables the antenna to move both along the azimuth and elevation. One of its axis is parallel to the local vertical and motions about it change the azimuth of the antenna. The azimuth can be varied from - 90° to 270° and the elevation from 0° to 95°. An air bearing aids the movement of the telescope along the azimuth. The antenna supported by six mild steel tubes ~~iron rods~~ rests on a highly polished annular granite surface making contact at three points. The shoes of this tripoid are hollow chambers. When air under pressure (1.5 kg/cm^2) is passed into the chamber, air escapes from the jets beneath the shoes and creates a pressure gradient. This lifts the aerial by about 5 to 10 μm above the granite surface and the antenna can be very easily moved over its air-cushion. The air bearing is an improvement over conventional ball bearings. The mechanical assembly is considerably simplified and the motion of the antenna is smooth and frictionless .

The radio waves received by the antenna are brought to the receiver by means of a quasi-optical beam wave guide system. Since it is impossible to place a bulky receiver at the prime focus, a secondary reflector,(a hyperbolid)is placed at the prime focus. This reflects the waves on to four plane metallic mirrors M_1 to M_4 inclined at 45° which finally focus the radiation into the receiver placed on the ground. (Refer Figure 1.4)

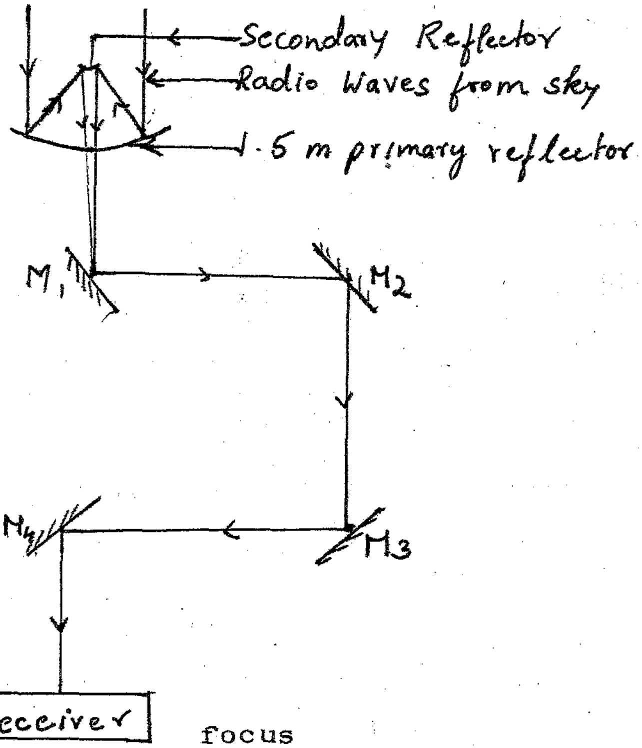


Fig. 1.4 Coude's ~~optical~~ focus arrangement for the 1.5 m Radio telescope

This arrangement is similar to Coude focus used in optical telescopes. The main advantage of this arrangement is that the position of the focus does not change with azimuth and elevation movement of the telescope.

1.3 Receiver

The purpose of the receiver is to select and amplify the weak signal received by the antenna and to provide an output signal to a digital recorder or other processing units. The accurate reproduction of the amplitude and spectral characteristics of the input signal is of prime importance. The radio receiver is in many respects similar to the one used in radio and television sets. It is extremely sensitive and stable. The requirements of a sensitive receiver are (i) the radio components should not themselves generate too much noise, (ii) the input should have a wide band width, (iii) the output should be averaged over as long a time as possible.

A simplified block diagram of a receiver along with the signal and spectrum at each stage is shown in the figure 1.5. The incident signal consists of noise which has a broad spectrum. A bandpass filter allows only a band of frequenc~~y~~ies Δf centered about the signal frequency f_o to pass through it. This signal is then mixed with the output of a local oscillator at f_{10} which shifts, the band down to an intermediate frequency f_i . The intermediate frequency signal which has the same

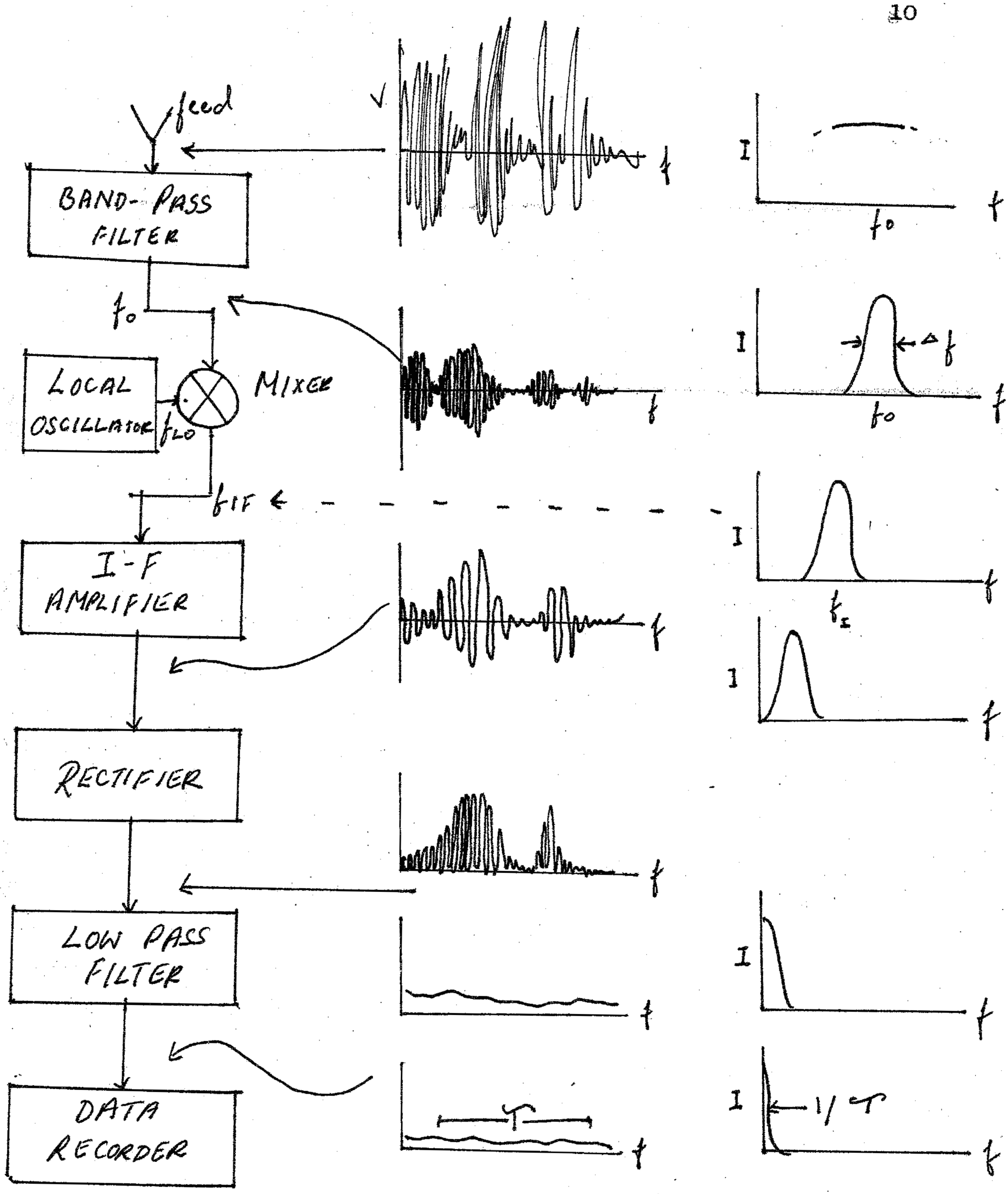


Fig. 1.5 A typical Radio receiver with signal and its frequency spectrum at each stage

spectral and intensity information as the original band is then amplified. The signal is further rectified to produce an unidirectional resultant. The signal is further smoothed out by circuit arrangements with an overall time constant τ greater than $1/\Delta f$. The resultant is relatively a constant as indicated in the receiver output meter. This output signal goes to the output recording device.

In the receiver used with the 1.5 m antenna (Refer Fig. 1.6) 110 GHz radio signal is first converted to an intermediate frequency of 1.4 GHz by beating it with a local oscillator signal at 111.4 GHz in a mixer. The 1.4 GHz signal is further down converted to a 2nd I.F. signal in the frequency band 10-400 MHz , which is then amplified, detected, digitized and then passed on to the computer for recording.

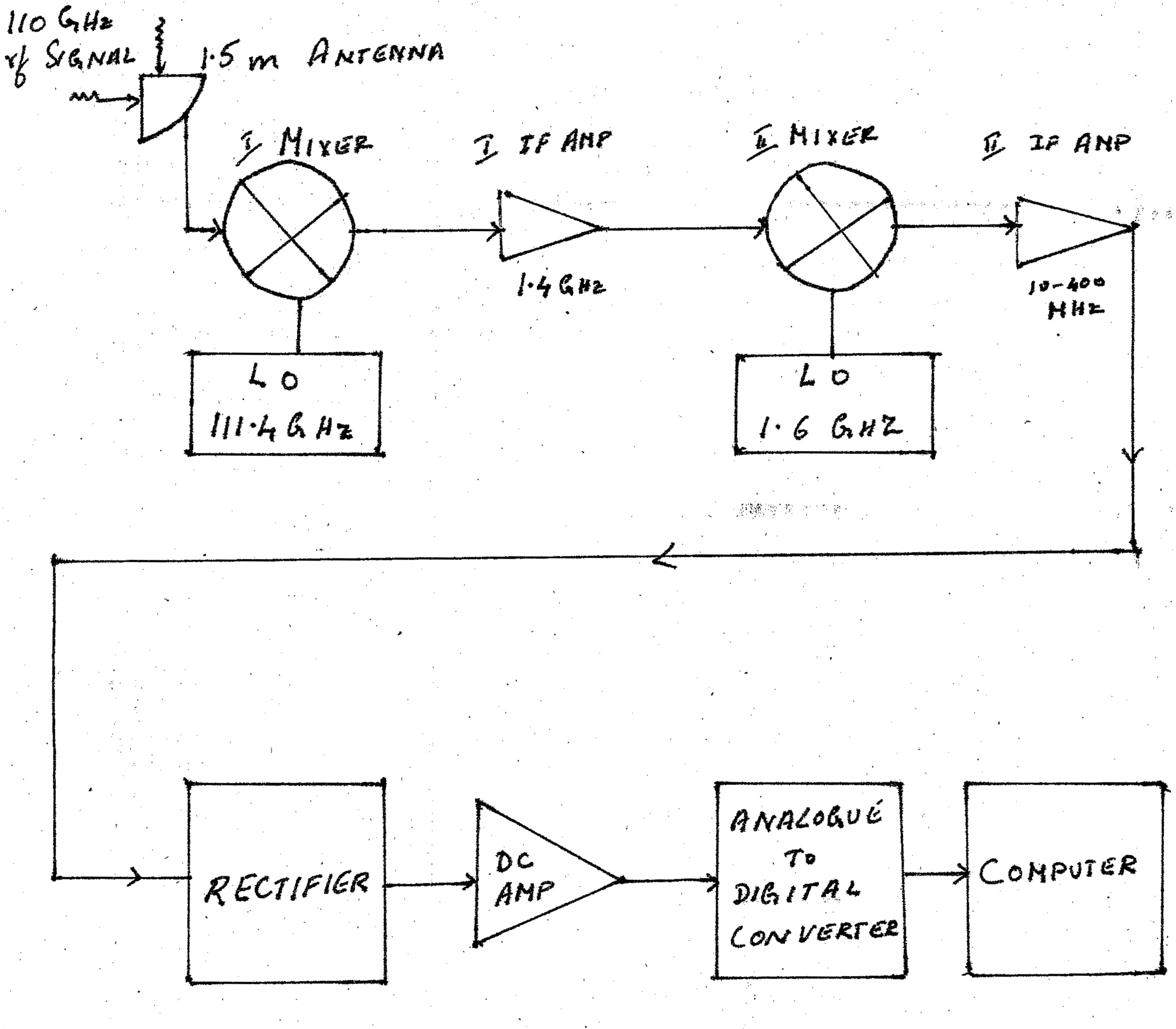


Fig. 1.6 Block diagram of the millimetre wave receiver at R.R.I.

1.4 Computer

The computer is the master control system. It not only records and analyses data but also controls the movement of the antenna and helps in tracking radio sources.

A mini computer LSI 11/23 is used for controlling the 1.5 m Telescope at R.R.I.

CHAPTER 2

OPTICAL DEPTH THEORY AND MEASUREMENT

2.1 Introduction

The propagation of radio waves through the earth's atmosphere is significantly affected by absorption and re-emission by atmospheric gases. As a result the antenna temperature recorded at the telescope is not equal to the source temperature and is given by

$$T_A = T_S e^{-\tau} + T_{atm} (1 - e^{-\tau}) \qquad (2.11)$$

where T_A is the antenna temperature, T_s the source temperature, T_{atm} the mean atmosphere ambient temperature of the atmosphere and τ the optical depth of the atmosphere or the opacity of the atmosphere to radio waves. THE OPTICAL DEPTH, τ IS A MEASURE OF THE TRANSPARENCY OF THE EARTH'S ATMOSPHERE TO RADIO WAVES COMING FROM OUTER SPACE.

For, $\tau = 0$, $T_A = T_S$

The observed brightness temperature at the antenna is the incident brightness temperature of the source for a transparent atmosphere.

For, $\tau = \infty$, $T_A = T_{atm}$

The observed brightness temperature is the temperature of the atmosphere for an opaque atmosphere. Therefore, an estimate of the value of τ is of great importance in radio astronomy.

$$\tau = \tau_0 \operatorname{Sec} Z \qquad (2.12)$$

Where τ_0 is the opacity for the zenith and Z the zenith angle. At the zenith the path travelled by the ray is minimum and hence opacity is minimum and $\tau = \tau_0$. At zenith angles greater than zero, the ray travels a greater distance and hence opacity increase

In the absence of a source, $T_s = 0$

$$T_A = T_{atm}\left(1 - e^{-\tau_0 \sec z}\right) \qquad (2.13)$$

With increasing Z, initially T_A increases rapidly and then saturates. Accounting for any stray radiation and receiver noise, the above equation reduces to

$$T_A = T_{S+R} + T_{atm}\left(1 - e^{-c_0 \sec z}\right) \qquad 2.14$$

where T_{StR} is constant. the frequency

2.2 Theoretical calculation

At 110 GHz, the frequency of operation of the 1.5 m telescope, the radio waves are strongly influenced by resonant absorption properties of the oxygen molecule which has a single isolated line at 118.75 GHz and the water molecule which has a much stronger pressure broadened line at 183 GHz (Refer Fig. 2.1)

$$\tau_\nu = \int_0^h k_\nu(h)\,dh. \qquad (2.21)$$

Where k_ν is the absorption co-efficient and is a function of the pressure, temperature and density of the absorbing substance. The volume absorption coefficient has units of km^{-1} and optical depth is a dimensionless quantity expressed in decibles (log to base 10) or nepers (log to base e).

$1\ N_p = 10 \log_{10} e.$

The oxygen spectial lines are due to the magnetic dipole transitions. Though these transitions are less intense than electric dipole transitions, the oxygen transition produces quite strong atmospheric absorption because of the large abundance of oxygen in the atmosphere.

$$k_{\nu_{O_2}} = 2.066 \frac{P}{T^3} \nu^2 \sum_k S_k e^{-2.068\, k(k+1)/T} \quad dB \cdot Km^{-1} \quad (2.22)$$

where $S_k = f_{k+} \mathcal{M}_{k+}^2 + f_{k-} \mathcal{M}_{k-}^2 + f_{k0} \mathcal{M}_{k0}^2$ (2.23)

$$f_{k\pm} = \frac{4 \nu_i^2 \Delta\nu}{(\nu_i^2 - \nu^2) + 4\nu^2 \Delta\nu^2} \quad (2.24) \; ; \quad f_{k0} = \frac{\Delta\nu}{\nu^2 + \Delta\nu^2} \quad (2.25)$$

$$\mathcal{M}_{k+}^2 = \frac{k(2k+3)}{k+1} \quad (2.26) \; ; \quad \mathcal{M}_{k-}^2 = \frac{(k+1)(2k-1)}{k} \quad (2.27)$$

$$\mathcal{M}_{k0}^2 = \frac{2(k^2+k+1)(2k+1)}{k(k+1)} \quad (2.28) \; ; \quad \Delta\nu = \left[\Delta\nu_c^2 + \Delta\nu_D^2\right]^{1/2} \quad (2.29)$$

$$\Delta\nu_c = 0.495 \frac{P}{T} \; GHz \quad (2.30) \; ; \quad \Delta\nu_D \;\; 6.33 \times 10^{-8} \nu_i T^{1/2} - (2.31)$$

The water vapour spectrum is due to the magnetic dipole transitions between rotational states of the molecule.

$$k_{\nu_{H_2O}} = 2.351 \times 10^{-5} \frac{\nu^2 P}{Q(T)} \sum_{ij} g_i \left(1 - e^{-.048\nu_i/T}\right) e^{-.948\nu_i/T} S_{ij} f(\nu\nu_{ij}) \quad dB\, km^{-1} \quad (2.32)$$

$$Q(T) = 172.4 \left[T/293\right]^{3/2} \quad (2.33)$$

$$f(\nu, \nu_{ij}) = \frac{4\nu_{ij}^2 \Delta\nu}{(\nu_{ij}^2 - \nu^2)^2 + 4\nu^2 \Delta\nu^2} \quad (2.34)$$

$$\Delta\nu = \left(\Delta\nu_c^2 + \Delta\nu_D^2\right)^{1/2} \quad (2.35) \; ; \quad \Delta\nu_D = 8.54 \times 10^{-8} \nu_{ij} T^{1/2} \quad (2.36)$$

$$\Delta\nu_c = \Delta\nu_{ij} \left(\frac{P}{1013}\right) \left(\frac{300}{T}\right)^{n_{ij}} \left(1 + .018 \frac{\rho T}{P}\right) - 2.37$$

In all these calculations P is the pressure in mb, T the temperature in K , P the water vapour density in g/m^3 . ν_{ij} the transition frequency in GHz and ν_i the frequency of the initial level.

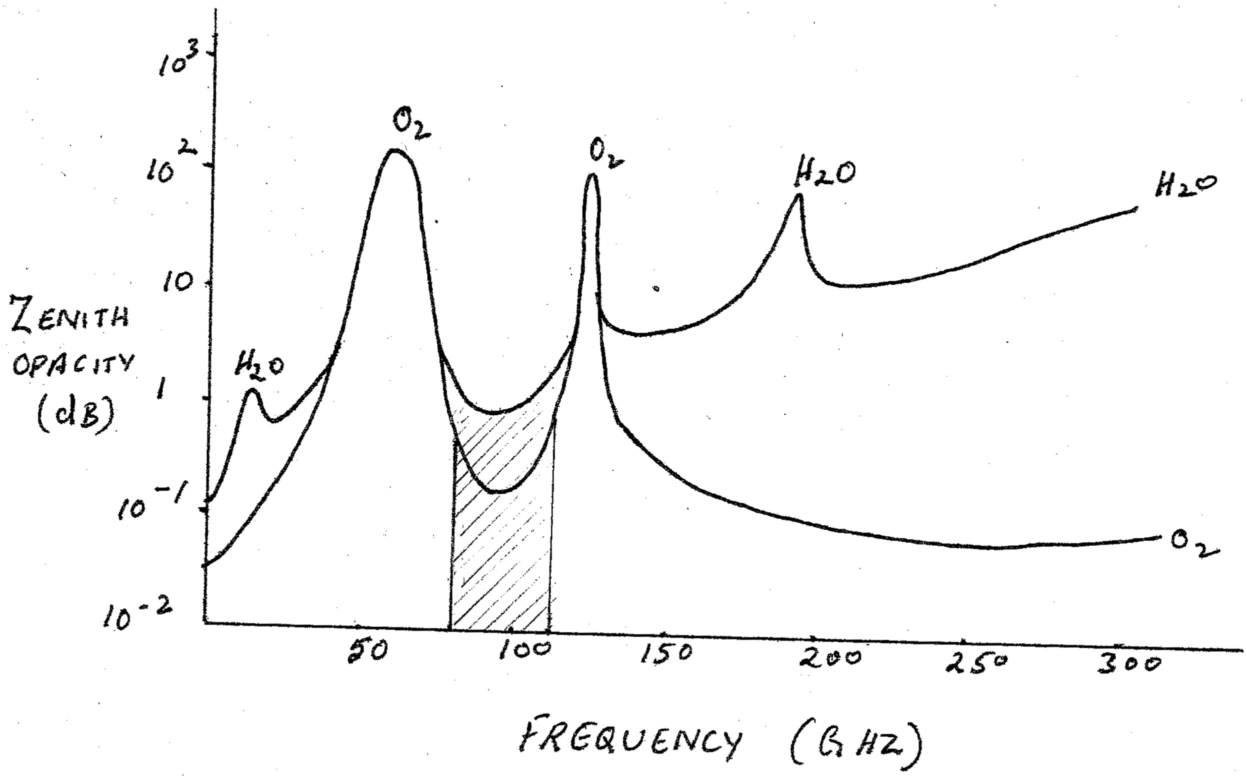


Fig. 2.1 Atmospheric Absorption of Millimetre Waves

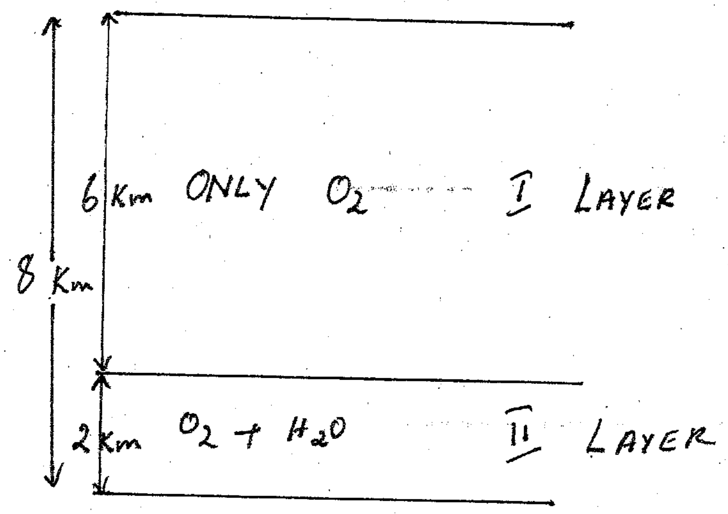


Fig. 2.2 Model of the atmosphere

A simple two layer model of the atmosphere as above in Fig. 2.2 can be used to calculate τ over a height of 8 kms above the surface of the earth beyond which the abundance of O_2 and H_2O vapour is almost negligible. Over the first layer complete absence of water vapour is assumed and k_ν for O_2 is calculated. Over the second layer k_ν for both oxygen and water vapour is calculated. k_ν over the first and second layers for oxygen gives τ_{oxy} and k_ν for water vapour in the second layer gives τ_{H_2O}. $\tau = \tau_{O_2} + \tau_{H_2O}$

The estimation of τ in this way is highly complex and critically dependent on the atmospheric model chosen and could be in error by as much as 50 % for the simple two layer model described above. Therefore an experimental approach was adopted for determining the value of τ.

2.3 Experimental Determination

The antenna is fixed at a particular azimuth where no radio source is present. The readings for various zenith angles either in steps of 5 or 10 degrees are obtained. The data is obtained from the computer controlled radio telescope by specifying the azimuth and the interval over which the altitude is varied.

A rough estimate of τ_0 can be made by using three readings Y_0, Y_{60}, and Y_{70}, at zenith angles 0°, 60°, and 70°.

We have, $Y_0 \propto T_{R+S} + T_{atm}(1-e^{-\tau_0})$ (2.31)

$Y_{60} \propto T_{R+S} + T_{atm}(1-e^{-2\tau_0})$ (2.32)

$Y_{70} \propto T_{R+S} + T_{atm}(1-e^{-3\tau_0})$ (2.33)

Subtracting (2.33) from (2.32), $Y_{60} - Y_{70} = T_{atm}(e^{-3\tau_0} - e^{-2\tau_0})$ -(2.34)

Subtracting (2.32) from (2.31), $Y_0 - Y_{60} = T_{atm}(e^{-2\tau_0} - e^{-\tau_0})$ -(2.35)

Dividing (2.35) by (2.34) $\dfrac{Y_0 - Y_{60}}{Y_{60} - Y_{70}} = e^{\tau_0}$

$$\tau_0 = \ln\left[\frac{Y_0 - Y_{60}}{Y_{60} - Y_{70}}\right] \qquad (2.36)$$

This gives only a rough estimate of τ_0 because the number of data points involved in the calculation are only three. Any error in one of these readings therefore could seriously affect the results. Incorporating the same idea but using all the data points we get

$$\frac{Y_Z - Y_{15}}{Y_{85} - Y_{15}} = \frac{e^{-\tau_0 \sec 15} - e^{-\tau_0 \sec Z}}{e^{-\tau_0 \sec 15} - e^{-\tau_0 \sec 85}} \qquad -(2.37)$$

The left hand side of equation (2.37) is calculated for all data points Y_Z and is plotted as a function Z. The R.H.S. is evaluated for various values of τ_0 and plotted as a function of Z. A comparison of the two plots gives the value of τ_0. This procedure was repeated by neglecting the value of Y_{85} and considering Y_{80} instead.

A computer program TAU FTN was written to obtain the R.H.S. of equation (2.37) F for the values of τ_0 ranging from 0.10 to 0.79.

2.4 Results and discussion

Observations were made in the months of December 1985 and January 1986. τ_0 was estimated for these data points using the method suggested in Section 2.3. The results have been tabulated in Table 1. The value of τ_0 in these months was found to vary between 0.1 and 0.3 which corresponds to a Zenith opacity of 0.4342 to 1.302 dB.

For a given set of data points, there was a large discrepancy between the values of τ_o obtained by considering Y_{85} and by neglecting Y_{85}. This could be because of the stray radiation from the nearby trees and buildings which is picked up by the antenna at lower elevations.

Also, the fit for the data points is not satisfactory. The possibility that an incorrect function has been assumed is ruled out as these equations are based on the principle of radiative transfer which is well established. This deviation may be due to two reasons.

1) The stray radiation is not a constant, but a function of elevation. As a result the data is corrupted and no longer follows the simple exponential function.

2) Inadequate method of analysis.

The errors involved in the scheme of analysis chosen could not be computed for lack of time.

TABLE I

	Observation		Calculation			
	Zenith angle	Receiver output	$\frac{Y_Z - Y_{15}}{Y_{85} - Y_{15}}$	R.H.S (2.37) $t_o = .19$	$\frac{Y_Z - Y_{15}}{Y_{80} - Y_{15}}$	R.H.S (2.37) $t_o = .10$
19th Dec. 85	85°	3.2177	1.0000	1.0000	-	-
	80°	3.1188	.7054	.6869	1.0000	1.0000
	75°	3.0432	.4800	.4820	.6804	.6544
	70°	3.0004	.3527	.3496	.5000	.4571
	65°	2.9553	.2181	.2590	.3092	.3310
	60°	2.9357	.1600	.1942	.2268	.2442
	55°	2.9150	.0984	.1459	.1391	.1816
	50°	2.9040	.0654	.1091	.0927	.1347
	45°	2.8955	.0400	.0805	.0567	.0987
	40°	2.8894	.0218	.0580	.0309	.0707
	35°	2.8857	.0109	.0401	.0154	.0488
	30°	2.8833	.0036	.0260	.0051	.0315
	25°	2.8820	0.0	0.0149	0.0	0.018
	20°	2.8820	0.0	0.0063	0.0	0.0076
	15°	2.8820	0.0	0.0	0.0	0.0
				$t_o = .30$		$t_o = .24$
21st Dec. 85	85°	3.2885	1.0000	1.0000	-	-
	80°	3.2617	.9233	.7921	1.0000	1.0000
	75°	3.1823	.6968	.5980	.7547	.7266
	70°	3.1079	.4843	.4522	.5245	.5378
	65°	3.0603	.3484	.3422	.3773	.4032
	60°	3.0285	.2578	.2627	.2792	.3047
	55°	3.0017	.1811	.2001	.1962	.2304
	50°	2.9821	.1254	.1511	.1358	.1731
	45°	2.9675	.0836	.1123	.0905	.1281
	40°	2.9589	.0592	.0813	.0641	.0925
	35°	2.9541	.0452	.0566	.0490	.0640
	30°	2.9467	.0243	.0367	.0264	.0416
	25°	2.9443	.0174	.0211	.0188	.0239
	20°	2.9382	0	.0090	0	0.01038
	15°	2.9382	0	0	0	0

	Observation		Calculation			
	Zenith angle	Receiver output	$\frac{Y_z - Y_{15}}{Y_{85} - Y_{15}}$	R.H.S (2.37) $\tau_o = .27$	$\frac{Y_z - Y_{15}}{Y_{80} - Y_{15}}$	R.H.S (2.37) $\tau_o = .23$
26th Dec. 85	85°	3.1933	1.0000	1.0000	-	-
	80°	3.1274	.7882	.7664	1.0000	1.0000
	75°	3.0651	.5882	.5679	.7462	.7217
	70°	3.0139	.4235	.4248	.5373	.5317
	65°	2.9785	.3098	.3210	.3930	.3979
	60°	2.9482	.2156	.2438	.2695	.3003
	55°	2.9284	.1490	.1850	.1890	.2268
	50°	2.9187	.1176	.1394	.1492	.1702
	45°	2.9174	.1137	.1034	.1442	.1259
	40°	2.9089	.0862	.0748	.1094	.0909
	35°	2.9003	.0588	.0519	.0746	.0630
	30°	2.8930	.0352	.0337	.0447	.0408
	25°	2.8833	.0039	.0193	.0049	.0234
	20°	2.8808	.0039	.0082	.0049	.0099
	15°	2.8820	0.0	0.0	0.0	0.0
				$\tau_o = .29$		$\tau_o = .22$
27th Dec. 85	85°	3.2116	1.0000	1.0000	-	-
	80°	3.1616	.8333	.7838	1.0000	1.0000
	75°	3.0908	.5975	.5881	.7170	.7168
	70°	3.0456	.4471	.4431	.5366	.5260
	65°	3.0102	.3292	.3365	.3855	.3927
	60°	2.9895	.2601	.2564	.3121	.2959
	55°	2.9724	.2032	.1951	.2439	.2232
	50°	2.9577	.1544	.1472	.1853	.1674
	45°	2.9485	.1138	.1093	.1365	.1237
	40°	2.9418	.0936	.07918	.1219	.0892
	35°	2.9345	.0772	.0550	.0926	.0618
	30°	2.9284	.0569	.0357	.0682	.0412
	25°	2.9223	.0365	.0205	.0439	.0230
	20°	2.9150	.0036	.0087	.0146	.0098
	15°	2.9113	0.0	0.0	0.0	0.0

	Observation		Calculation			
	Zenith angle	Receiver output	$\frac{Y_Z - Y_{15}}{Y_{85} - Y_{15}}$	R.H.S (2.37) t_o = .22	$\frac{Y_Z - Y_{15}}{Y_{80} - Y_{15}}$	R.H.S(2.37) t_o = .16
28th Dec. 85	85°	3.1701	1.0000	1.0000	-	-
	80°	3.115	.7551	.7185	1.0000	1.0000
	75°	3.0578	.5306	.5150	.7027	.6863
	70°	3.0175	.3622	.3780	.4797	.4917
	65°	2.9956	.2704	.2822	.3581	.3616
	60°	2.9772	.1956	.2126	.2567	.2696
	55°	2.9638	.1377	.1604	.1824	.2019
	50°	2.9565	.1071	.1202	.1418	.1506
	45°	2.9492	.0765	.0889	.1013	.1109
	40°	2.9467	.0663	.0641	.0878	.0797
	35°	2.9382	.0306	.0444	.0405	.0561
	30°	2.9357	.0204	.0288	.0270	.0356
	25°	2.9370	.0255	.0159	.0337	.0204
	20°	2.9321	.0051	.0068	.0067	.0086
	15°	2.9309	0.0	0.0	0.0	0.0
				t_o = 14		t_o = .1
30th Dec. 85	85°	3.2019	1.000	1.000	-	-
	80°	3.1237	.6751	.6298	1.000	1.000
	75°	3.0761	.4771	.4275	.7067	.6544
	70°	3.0285	.2791	.3024	.4135	.4571
	65°	3.0053	.1827	.2213	.2706	.3310
	60°	2.9870	.1066	.1644	.1578	.2442
	55°	2.9797	.0761	.1228	.1127	.1816
	50°	2.9748	.0558	.0914	.0827	.1347
	45°	2.9724	.0456	.0672	.0676	.0987
	40°	2.9699	.0353	.0483	.0523	.0707
	35°	2.9785	.0710	.0333	.1052	.0488
	30°	2.9663	.0203	.0215	.03007	.0315
	25°	2.9663	.0203	.0123	.0300	.0 18
	20°	2.97485	.0558	.0052	.0827	.0076
	15°	2.96142	0.0	0.0	0.0	0.0

	Observation		Calculation			
	Zenith angle	Receiver output	$\frac{Y_Z - Y_{15}}{Y_{85} - Y_{15}}$	R.H.S (2.37) $\tau_o = .18$	$\frac{Y_Z - Y_{15}}{Y_{80} - Y_{15}}$	R.H.S (2.37) $\tau_o = .18$
31st Dec. 85	85°	3.1982	1.0000	1.0000	-	-
	80°	3.0957	.6956	.6647	1.0000	1.0000
	75°	3.0261	.4891	.4596	.7031	.6544
	70°	2.9809	.2957	.3306	.5150	.4571
	65°	2.9467	.2536	.2438	.3645	.3310
	60°	2.9246	.1884	.1821	.2708	.2442
	55°	2.9077	.1376	.1365	.1979	.1816
	50°	2.8955	.1014	.1019	.1458	.1347
	45°	2.8881	.0797	.0751	.1145	.0987
	40°	2.8820	.0615	.0540	.0885	.0707
	35°	2.8771	.0471	.0373	.0677	.0488
	30°	2.8696	.0253	.0242	.0365	.0315
	25°	2.8710	.0289	.0139	.0416	.0180
	20°	2.8698	.0253	.0059	.0364	.0076
	15°	2.8603	0.0	0.0	0.0	0.0
				$\tau_o = .14$		$\tau_o = .14$
2nd Jan. 86	85°	3.0480	1.0000	1.0000	-	-
	80°	2.9418	.6704	.6298	1.0000	1.0000
	75°	2.8759	.4659	.4257	.6949	.6758
	70°	2.8308	.3257	.3024	.4858	.4802
	65°	2.7929	.2083	.2213	.3107	.3513
	60°	2.7758	.1553	.1644	.2316	.2611
	55°	2.7624	.1136	.1228	.1694	.1950
	50°	2.7575	.0984	.0914	.1468	.1452
	45°	2.7514	.0795	.0672	.1186	.1067
	40°	2.7392	.0416	.0483	.0621	.0767
	35°	2.7392	.0416	.0333	.0621	.0529
	30°	2.7331	.0227	.0215	.0264	.0342
	25°	2.7355	.0303	.0123	.0451	.0195
	20°	2.7307	.0151	.0052	.0225	.0083
	15°	2.7258	0	0	0	0

	Observation		Calculation			
	Zenith angle	Receiver output	$\frac{Y_Z - Y_{15}}{Y_{85} - Y_{15}}$	R.H.S (2.37) $\tau_o = .24$	$\frac{Y_Z - Y_{15}}{Y_{80} - Y_{15}}$	R.H.S (2.37) $\tau_o = .18$
3rd Jan. 86	85°	3.2141	1.0000	1.000	-	-
	80°	3.1420	.7838	.7384	1.000	1.000
	75°	3.0651	.5531	.5366	.7056	.6966
	70°	2.9992	.3553	.3968	.4532	.5032
	65°	2.9736	.2783	.2977	.3551	.3719
	60°	2.9687	.2637	.2250	.3364	.2783
	55°	2.9455	.1941	.1702	.2476	.2089
	50°	2.9235	.1282	.1278	.1635	.1561
	45°	.29174	.1098	.0946	.1401	.1151
	40°	2.9077	.0805	.0683	.1028	.0828
	35°	2.9040	.0695	.0474	.0887	.0573
	30°	2.8857	.0146	.0376	.0186	.0371
	25°	2.8845	.0109	.0176	.0140	.0212
	20°	2.8820	.0036	.0075	.0046	.0090
	15°	2.8808	0.0000	0.0	0.0	0.0

Graphs :-

Y axis : $\frac{Y_{z} - Y_{15}}{Y_{85/80} - Y_{15}}$

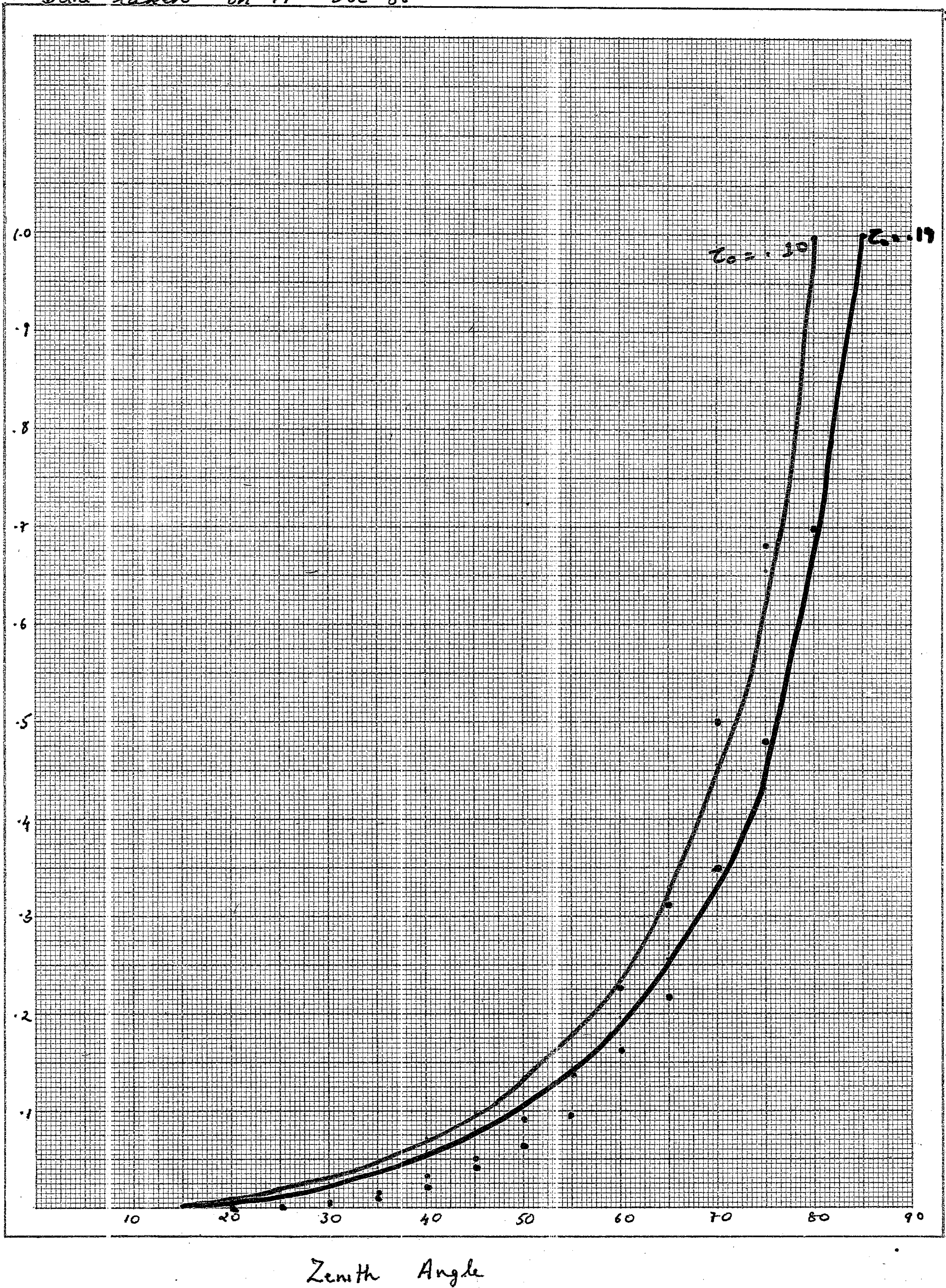
—— A plot of the R.H.S of eq 2.37 neglecting Y_{85}

• • • • • experimental points ~~considering~~ neglecting Y_{85}

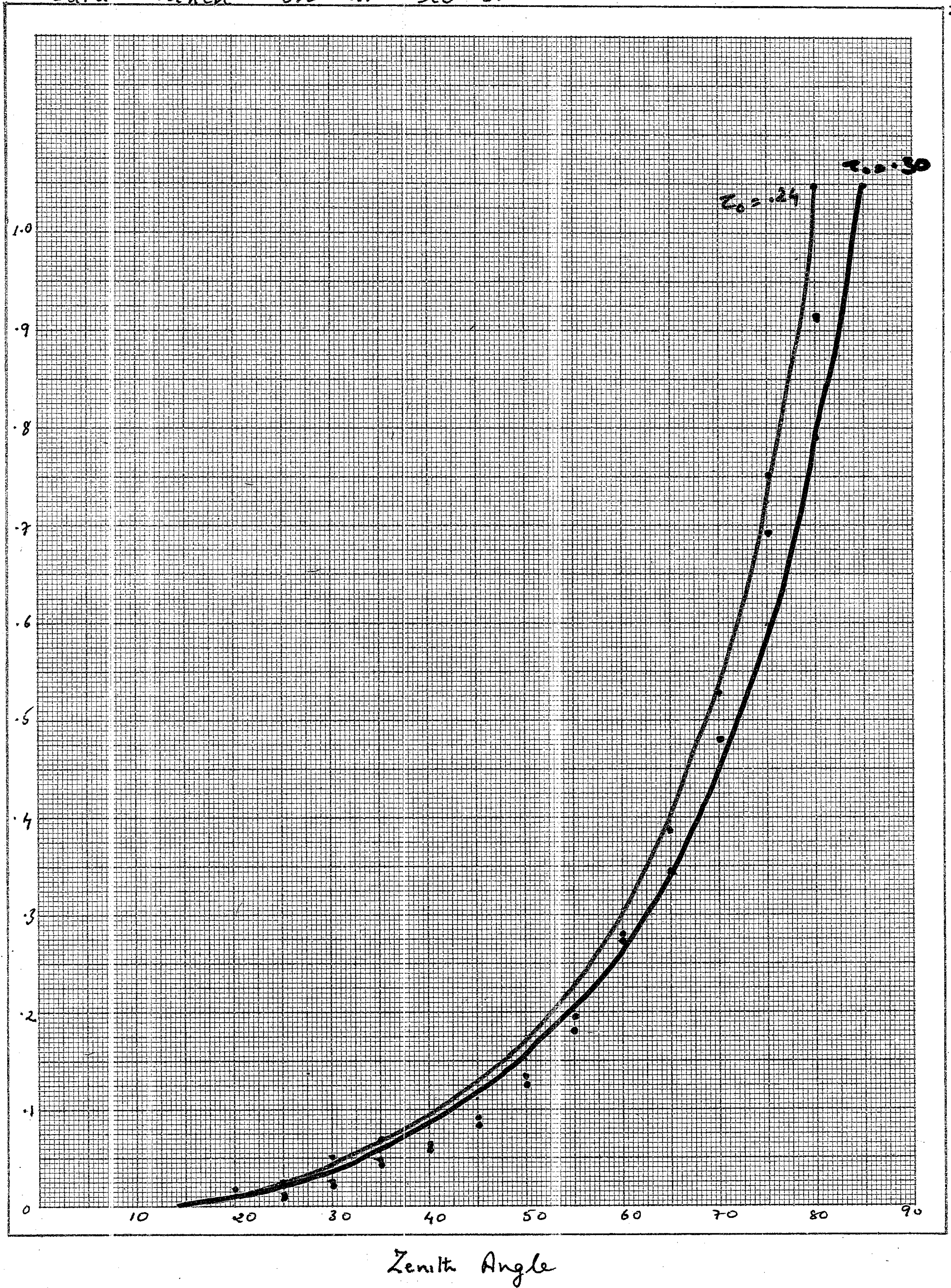
—— A plot of the R.H.S of eq 2.37 considering Y_{85}

• • • • • experimental points considering Y_{85}

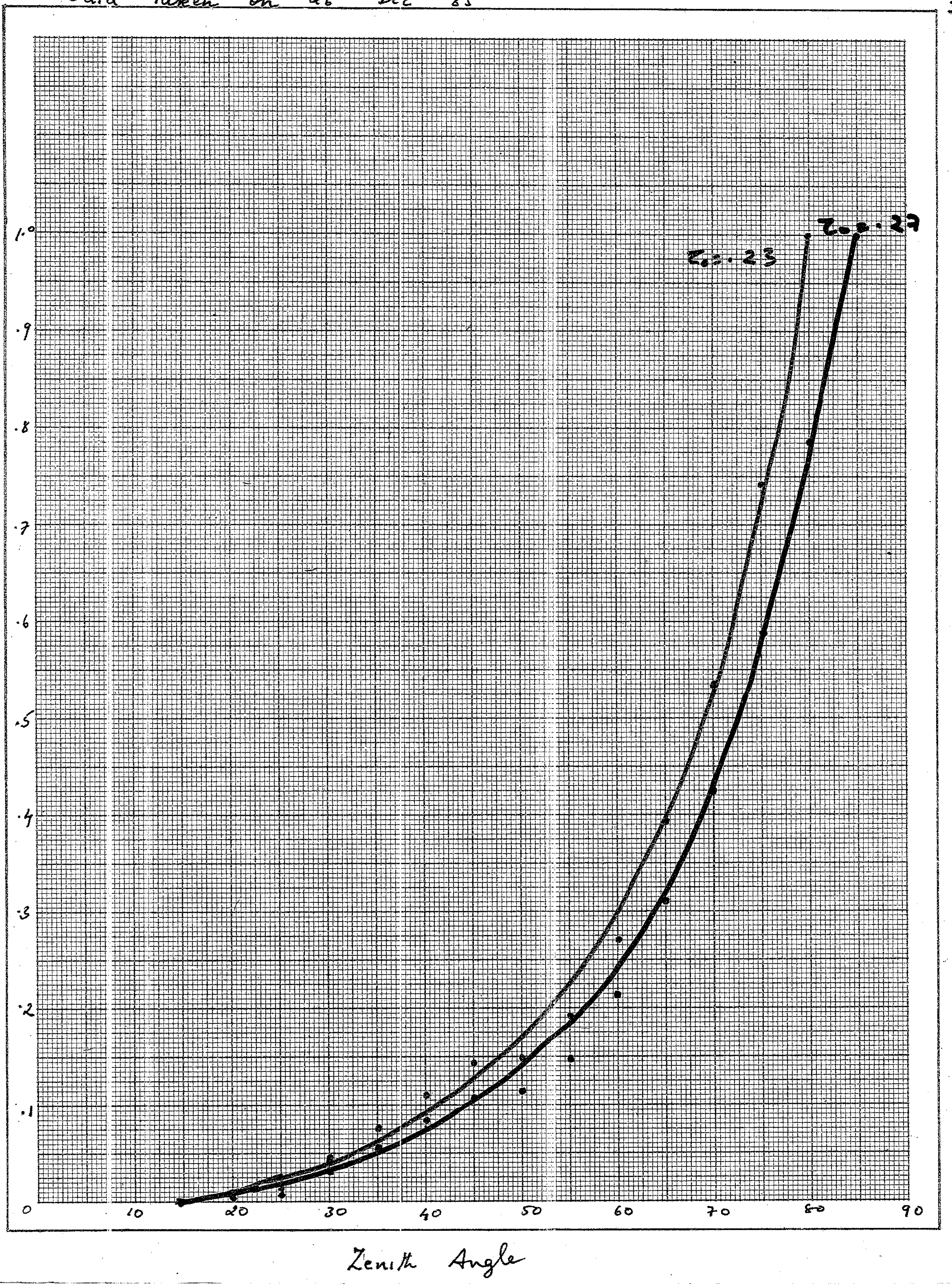
Data taken on 19th Dec '85



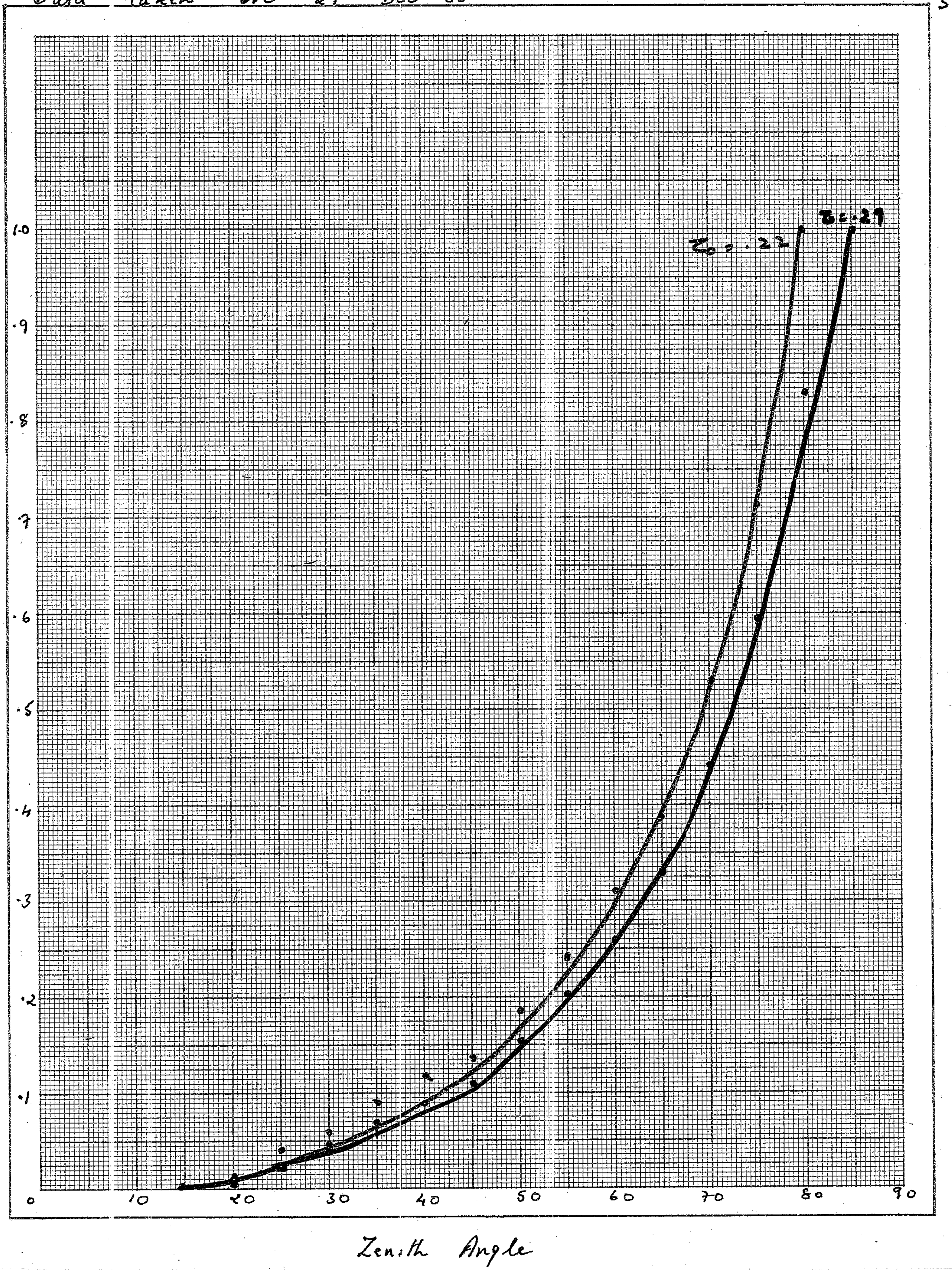
Data taken on 21st Dec 85



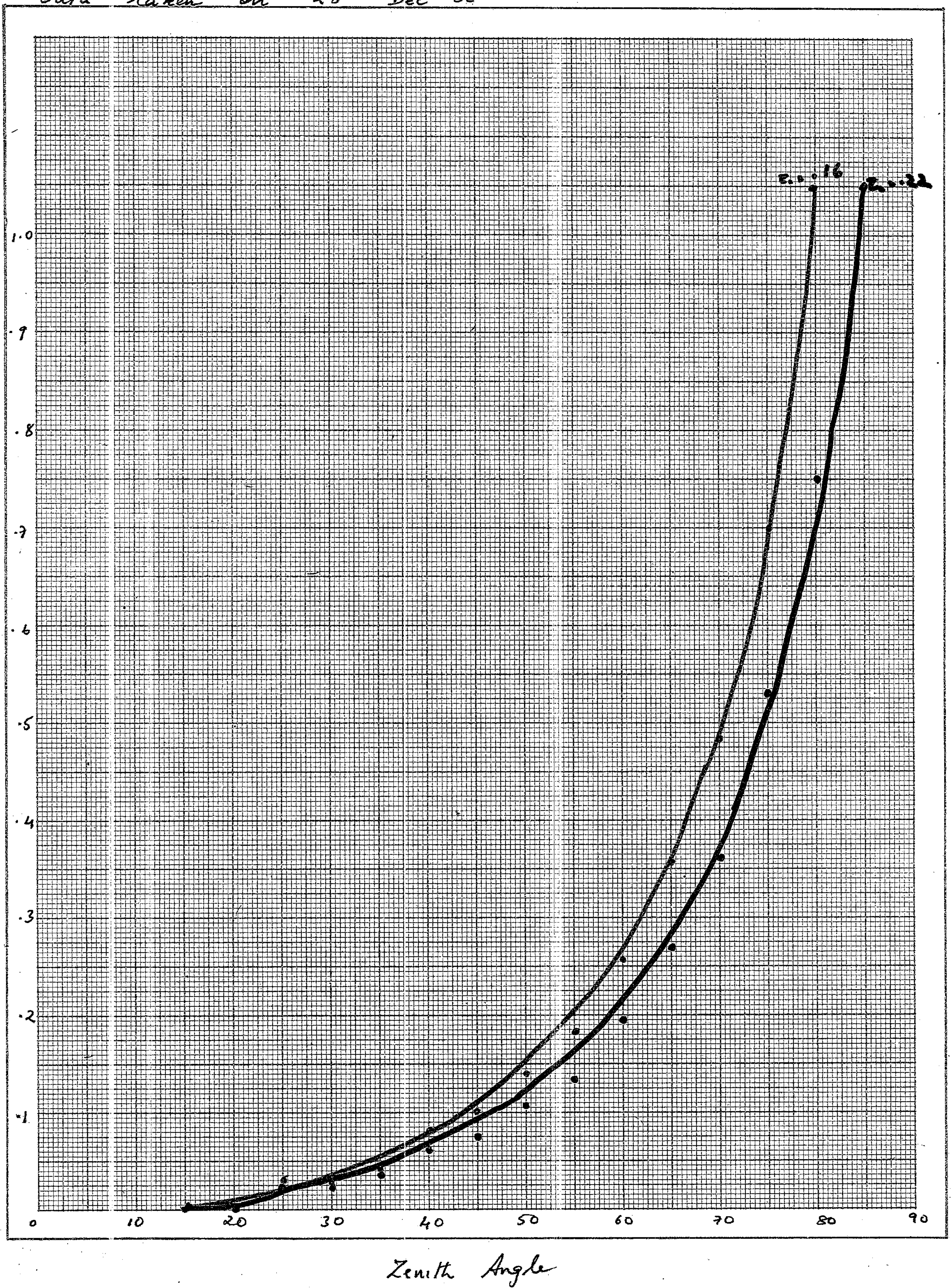
Data taken on 26th Dec '85



Data taken on 27th Dec '85



Data taken on 28th Dec '85



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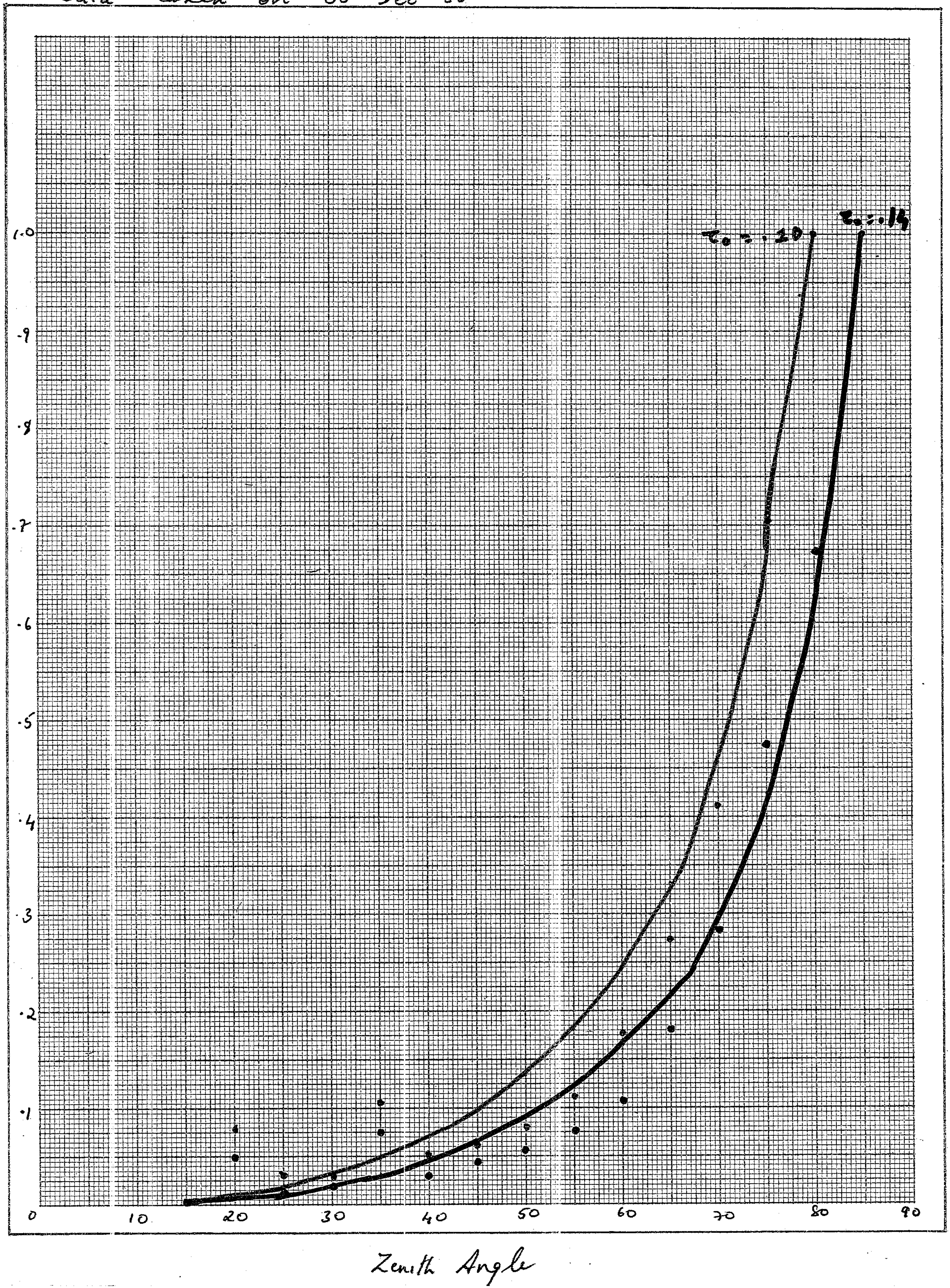
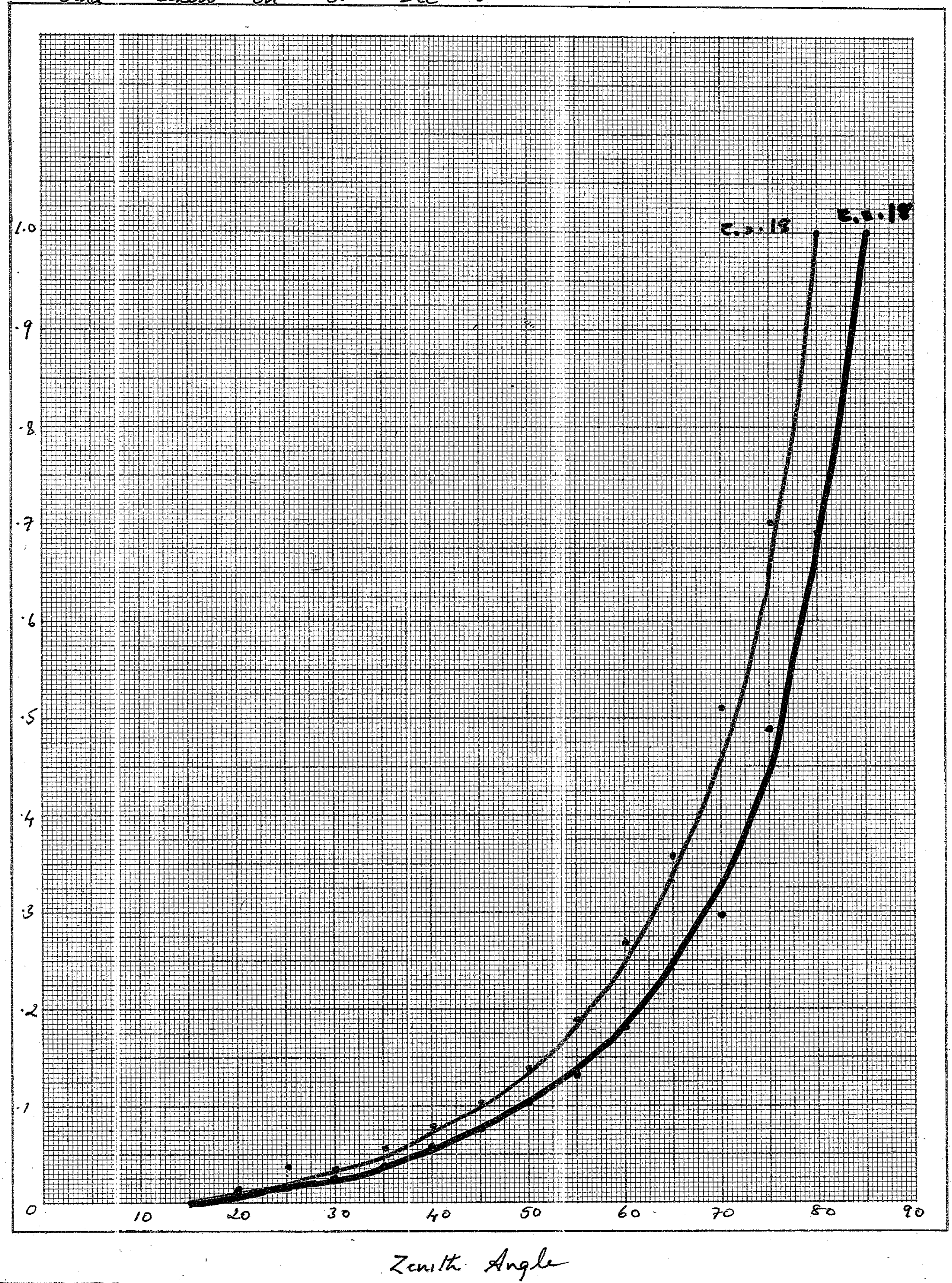
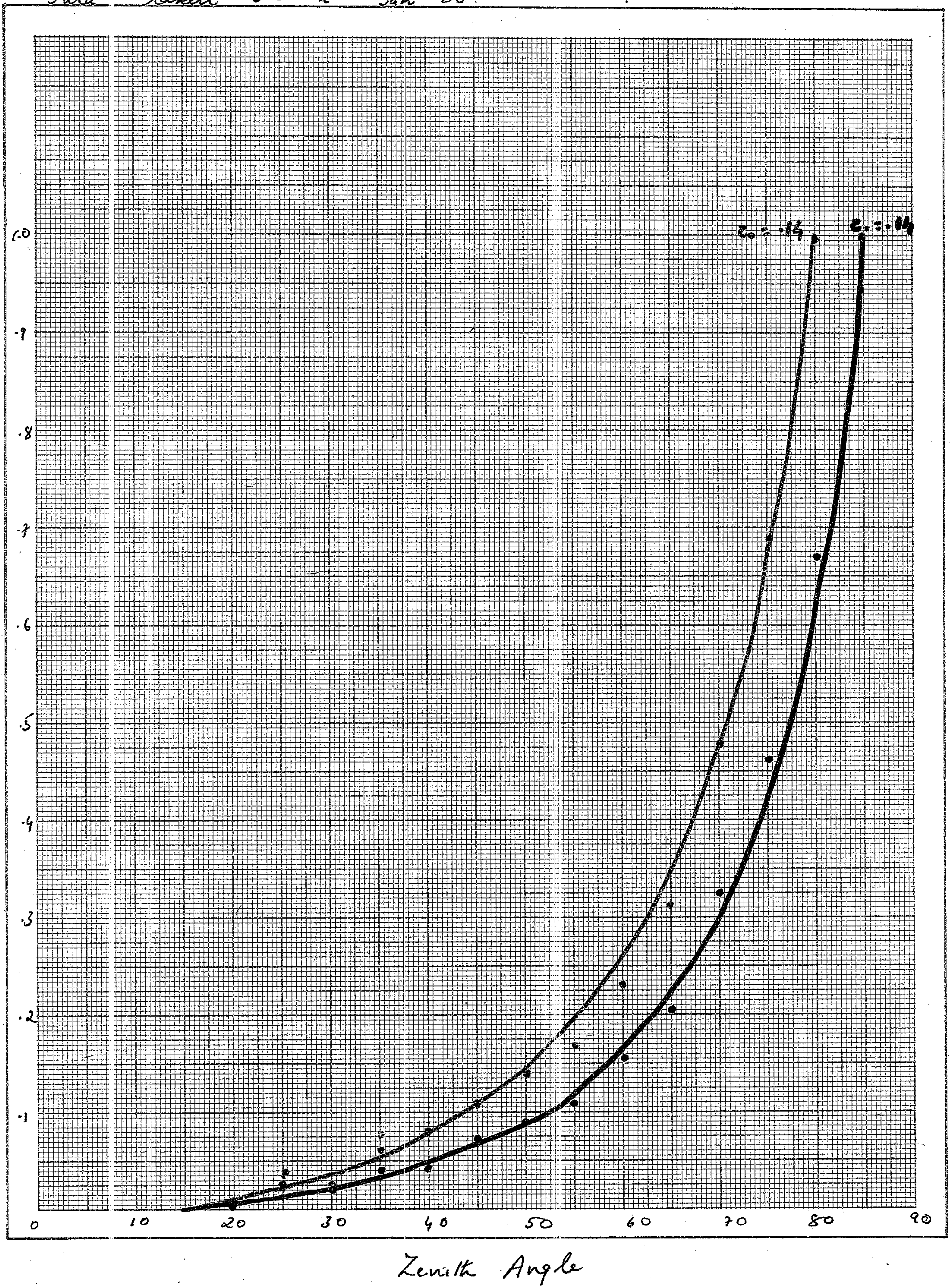


Data taken on 31st Dec '85



Data taken on 2nd Jan '86.



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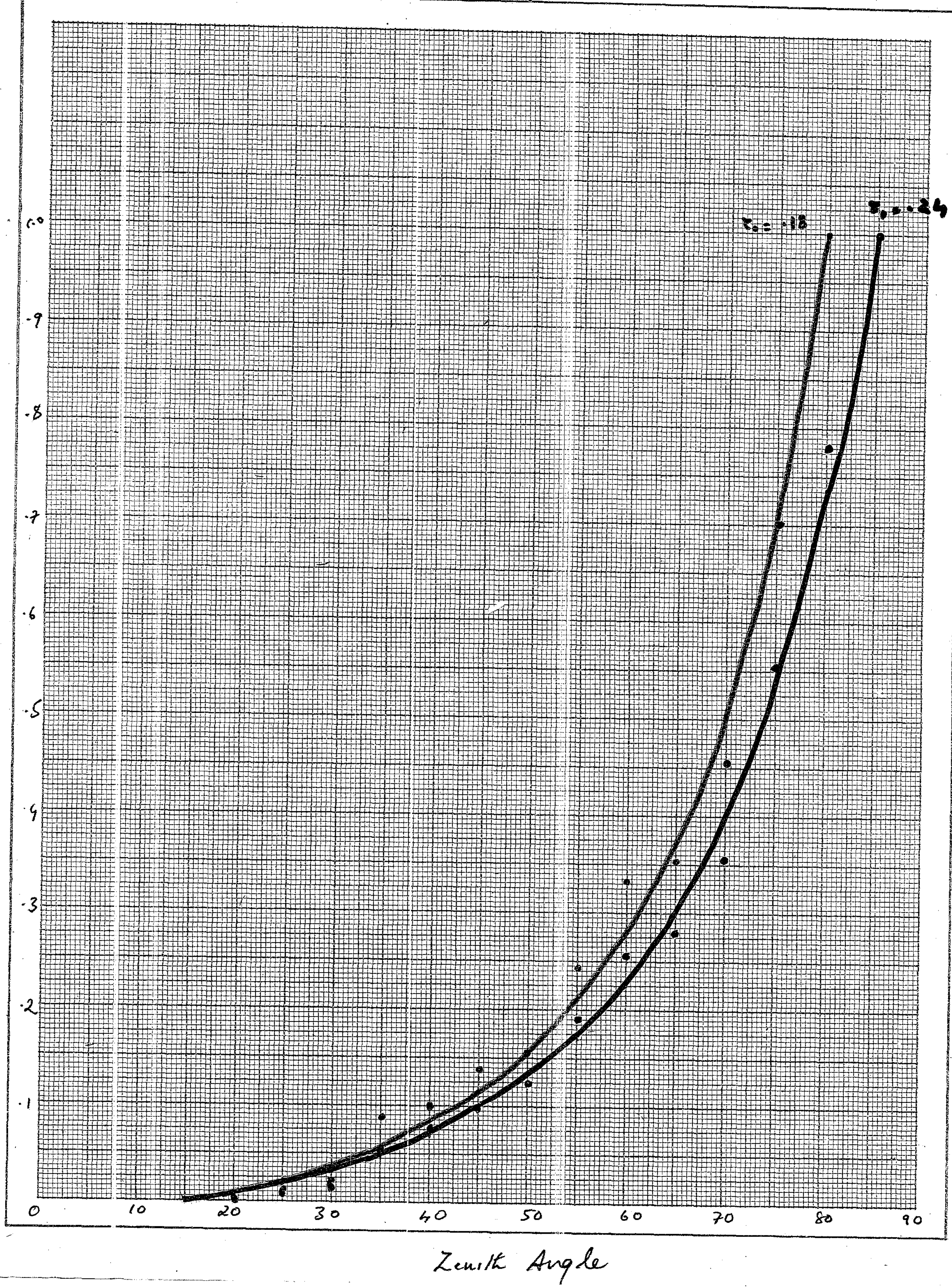

APPENDIX 1

Antenna Temperature T_A :

is the temperature of a passive network which in the frequency band Δf has a mean available noise power due to the thermal agitation equal to the available power at the aerial terminal.

The antenna temperature has contributions from (i) the antenna temperature of the source T_s (ii) the antenna temperature $T_{B.G}$ attributed to the radio background on which the source is measured (iii) Power received by the antenna from outside its primary beam ie., due to from side lobes - $T_{S.L}$ (iv) the antenna temperature caused by the radiation produced in the atmosphere - T_{atm} .

$$T_A = T_S + T_{B.G} + T_{S.L} + T_{atm} \qquad (1)$$

Beam width :

is defined as the angle between the direction corresponding to half the maximum sensitivity.

sensitivity

Brightness :

For a source distributed over the sky, the strength is measured by brightness

$$b = \lim_{\Delta\Omega \to 0} \frac{\Delta S}{\Delta\Omega} \quad \text{watts } m^{-2}\ Hz^{-1}\ st^{-1} = \text{Jensky } st^{-1} \qquad (2)$$

where ΔS is the total flux received in the solid angle of the cone whose vertex is at the receiving point.

Brightness Temperature:

It is the temperature of the black body for which the brightness of the thermal radiation would equal that which is actually observed.

$$I_{\nu} = \frac{2kT\nu^2}{c^2} \qquad (3)$$

Where T is the brightness temperature.

Directivity:

is defined as the ratio of the maximum radiation intensity from the source under consideration to the radiation intensity from an isotropic source radiating the same power. For an lossless isotropic antenna, directivity D is ~~one~~ given as

$$D = \frac{\text{max radiation intensity}}{\text{average radiation intensity}}$$

Flux density :

is the measure of the strength of a discrete source. If ΔE is the energy in the frequency range Δf flowing through an area ΔA in time ΔT, $\Delta T \gg \frac{1}{\Delta f}$, then the flux density S is given by

$$\Delta E = S \, \Delta A \, \Delta f \, \Delta T \quad \text{Jensky} \qquad (5)$$

Gain:

is defined as the ratio of the maximum radiation intensity from the subject antenna to the radiation intensity from an isotropic source with the saurce power input. It is the increase in power we receive in the beam as compared with an imaginary aerial having the same sensitivity in all directions.

$$G = k D \qquad (6)$$

where k is the radiation efficiency factor.

APPENDIX 2

```
C    PROGRAM TO CALCULATE R.H.S. OF EQUATION 2.37 FOR
     VALUES OF TAU = 0.10 TO 0.79
     DIMENSION  C (17)
     REAL NZ
     PI = 0.01745329
     DO  10   I = 1,7 F
     P  = I / 10.
     DO  10  J = 1, 10
     PP = (J-1.) / 100.
     T  = P + PP
     PRINT  * ,  'TAU'
     Q  = T /COS (15. * PI)
     QQ = T /COS (85. * PI)
     X  =  EXP (-Q)
     Y  =  EXP (-QQ)
     Z  =  X - Y
     DO  11  N = 3, 17
     NZ  = N * 5.
     A  = T / Cos (NZ * PI)
     B  = EXP (-A)
     C (N) = (X-B) / Z.
11   CONTINUE
     PRINT * , (C(NN), NN = 3,17)
10   CONTINUE
     STOP
     END
```

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