Analysis Using Standard Isotherms

Standard isotherms admittedly do not yield the surface area values by themselves. However, they are probably the most useful of the methods of analysis. The question as to why one would use an analysis that does not yield a value for the surface area may seem puzzling. Firstly, there are times when all one really needs is a relative value. Secondly, the isotherms are useful for extrapolation and as input into various theories, such as porosity calculations. Most absolute numbers for surface area from these isotherms refer back to the BET equation for standardization. With a good well characterized standard, which includes a knowledge of the surface area, which in most cases is very hard to obtain, one can obtain values for surface area and porosity.

There are now several standard isotherms. However, the two used the most are still the α-s standard isotherms and the t-thickness isotherm. The standard t-thickness isotherm on alumina may, however, be slightly inaccurate at the higher pressures. There is a tendency today to construct a standard isotherm for the adsorbent-adsorbate pair being used. This is a bit tricky since these standard isotherms are usually used for porosity measurements and to obtain a nearly flat surface that is energetically the same as the porous material seems unlikely. Never-the-less, it often seems to work.

The standard curve method follows these steps:

1. Measure an isotherm on a known material. In the case of silica and alumina and other

materials mentioned in a later chapter, this has already been done.

2. Obtain the amount adsorbed as a function, **F**, of relative pressure, $x = P/P_s$ or:

$$n_{\text{ads}} = A_{\text{s}}\,\mathbf{F}\left(x, T\right) \qquad \textbf{(116)}$$

Normally this curve is measured at only one temperature. If one knows the surface area of this standard, then the value of **F** is scaled so that A_s in the above equation is the surface area value of the standard.

3. Plot the n_{ads} of the unknown sample against the function **F**.
4. Calculate the surface area of the unknown as the slope times the known A_{s}.

Principal Problem with Standard Curves

The main problem involved with the standard curves is that the surface area, or monolayer equivalent, is not specified by the technique itself. If one had a standard curve that had a calibration for the surface area, then the implications of these curves, calculations of the porosity and energies, would be valid. This is, however, not the case. The traditional solution to this problem is to use the BET surface area, which introduces a large uncertainty in precision and a very large, at least a factor of 2. (See Appendix II H page 312 for an explanation and some calculations)

It is a bit ironic that the standard curves normally use the value of $P/P_{\text{vap}} = 0.4$ to make comparison which is outside the BET range or 0.05 to 0.35. This introduces a probably small degree of uncertainty, perhaps less than 4%. This is quite small compared to the minimal absolute error of 118%.

Because of these considerations, in the tables that follow both the BET surface area number and the quantum mechanical number for specific surface area. In addition QM value for E_{a} is also provided. There is the proviso for this that these are provide if the physical quantities for the original data are available.

Standard Isotherms

Isotherms measured on well characterized material and are used for comparison with isotherms of unknowns are referred to as standard isotherms. Tables of a variety of standard isotherms that are described here are presented in the next section. The values of n_{m} and χ_c are presented with the data tables.

- The α_{s}-Curve Standard (see Sing, Everett and Ottewill [6]) -

The α_{s}-curve has an advantage that the original data has not been severely reworked. Originally these plots were simple *n*-plots (i.e., number of moles adsorbed as a function of pressure.) The procedure for obtaining these curves was to obtain a multiplicity of adsorption isotherms on many powders of the same type of material. The value for n_{m} and the surface area, however, is based on the BET surface area. Therefore these values carry all the uncertainties of the BET method. An alternative method of determining n_{m} that is more reliable would be better. These standard curves are very useful for porosity determinations due to the high degree of confidence

in the basic standard curve. For the α_s-curve is an averaged and smoothed curve for several similar silica samples is used. Generally, in the literature it works quite well, even in the high pressure range. Curves for both nitrogen and argon are available.

The data in **Table 10** are some data by Bhambhani, Cutting, Sing and Turk[37] and quoted in the book by Everett, Parfitt, Sing, and Wilson[38]. From the BET value, one may back calculate the original data. There is some uncertainty in this conversion so the original numbers are present in case someone can discern what the conversion actually is.

Table 12 presents some more data by Payne, Sing and Turk[39] also for silica. In **Table 13** are the α-s curves normalize to the value of P/P_s of 0.4[40].

- The t-Curve -

One of the earliest standard curves was the t-curve by Lippens, Linsen and deBoer[41], which was the adsorption of N_2 on alumina. The data were reported in terms of film thickness in angstroms (unit designator Å and equal to 10^{-10}m). In **Table 14** are the data for both the smoothed curve and the original data. The conversion from volume adsorbed in mL g^{-1} is given by the equation

$$t = 3.54\left(V/V_{\mathrm{m}}\right)\text{Å} \qquad \textbf{(117)}$$

- IUPAC Standards on Silica and Carbon -

The original purpose of the IUPAC (compiled by Everett, Parfitt, Sing, and Wilson [42]) round-robin investigation was to create some confidence in the methodology of adsorption isotherm measurements. Standard samples from the same productions batches were used and various laboratories performed the same experiments. The results were not intended as standard curves but the agreement between the various laboratories was generally very good, within 2 %. Therefore, these would be as good standards as one would be able to find. Apparently, the archive for these standards no longer exists. The data presented below was extracted from the literature from laboratory "H". This seemed to be a typical data run. The isotherms determined were for Gisil silica, TK800 silica, (silica in ?) Vulcan 3G carbon and Sterling FT carbon (carbons in **Table 14**).

- RMBM Carbon Standard -

A standard adsorption isotherm curve for activated carbon has been published by Rodriguez-Reinoso, Martin-Martin, Prado-Burguete and McEnaney[43](RMBM) The data and the α_s standard are presented in **Table 15**. The carbon studied was an activated carbon form and contained macropores and micropores[44]. The micropores were closed by heating to 2073 K[45]. The value for A_s was obtained from the BET surface area and was reported to be 4.3 - 4.4 m^2 g^{-1}. This curve is a smoothed curve and at the low pressure range is very different from other standards. In the literature, there are several standards for carbon. There is probably an appropriate standard available for the carbon material of particular interest.

- KFG Segmented Standard Carbon Curve (by Karnaukhov, Fenelonov and Gavrilov) -

Karnaukhov, Fenelonov and Gavrilov[46] have presented a standard curve with a segmented least squares fit to the data of α versus P/P_s. The fit is for the equation:

$$n_{\text{ads}} = \sum_{i=0}^{5} C_i \left[\ln\left(\frac{P_s}{P}\right) \right]^i \qquad \textbf{(118)}$$

Table 16 lists the coefficients. C_i. n_{ad} is given here in units of μmol m^{-2} but the surface area per gram of sample is not listed. In order to use this in the usual fashion a table of α-s for this is constructed in **Table 17**. This curve may be useful for determining mesoporosity. It does not extrapolate below 0.10 P/P_s.

- Cranston and Inkley Standard for Pore Analysis -

Cranston and Inkley[47] developed a general standard isotherm which did a fair job for a variety of adsorbents including silica and alumina. Basically, the data was averaged and smoothed to yield the standard curve. The data for this curve is not presented in their article but a graph of the averaged isotherm is given. It would be best for those who wish to use this curve to consult the original.

- Thoria Standard Curves -

Thoria has the interesting property that it can be fired to a high temperature without changing morphology. Thus, a degassing temperature to clean the surface at 1000°C does not change the surface area. It is therefore an interesting research tool and is used for a variety of commercial applications. In **Table 18** is the standard nitrogen curves for thoria obtained by Gammage, Fuller and Holmes[48] for thoria out-gassed at 25°C. For higher out-gassing temperatures, the standard curve is the same at high values of χ (high relative pressure) but deviates with a chi-plot break, at a low value of χ. This is due to the degassing of a higher energy plane. The original smoothed curve has been made into a α-s curve. In **Table 19** is the standard curve for water on thoria. A similar treatment has been used for the smoothed curve. The standard curve for argon adsorption is listed in **Table 20**.

- Standard Curves for Lunar Soil -

In **Table 22** through **Table 24** are the standard isotherms from lunar soil as supplied to NASA[49]. For these samples the standard curves have been converted here to α-s curves. The first three points were ignored for the α-s curve fit for oxygen adsorption. The reason for the zero values is discussed in the section of the threshold phenomenon. Details about the lunar soils can be obtained in a US government report[50] and addition information available from an article by Fuller[51].

Tables of standard isotherms

Table 10 Data analysis of N_2 α-s curves on silica from Bhambhani, Cutting, Sing and Turk.

P/P_{vap}	χ	n_{ads} /mol m^{-2}	n_{ads} mmol g^{-1}	n_{ads} fit	P/P_{vap}	χ	n_{ads} /mol m^{-2}	n_{ads} mmol g^{-1}	n_{ads} fit
0.001	-1.933	4.0	0.155	0.162	0.26	-0.298	13.3	0.526	0.532
0.005	-1.667	5.4	0.209	0.220	0.28	-0.241	13.6	0.538	0.544
0.01	-1.527	6.2	0.240	0.251	0.30	-0.186	13.9	0.550	0.556
0.02	-1.364	7.7	0.298	0.286	0.32	-0.131	14.2	0.561	0.568
0.03	-1.255	8.5	0.329	0.310	0.34	-0.076	14.5	0.573	0.580
0.04	-1.169	9.0	0.348	0.329	0.36	-0.021	14.8	0.584	0.591
0.05	-1.097	9.3	0.360	0.345	0.38	0.033	15.1	0.600	0.603
0.06	-1.034	9.4	0.364	0.358	0.40	0.087	15.5	0.604	0.615
0.07	-0.978	9.7	0.375	0.371	0.42	0.142	15.6	0.623	0.627
0.08	-0.927	10.0	0.387	0.382	0.44	0.197	16.1	0.635	0.639
0.09	-0.879	10.2	0.395	0.392	0.46	0.253	16.4	0.658	0.664
0.10	-0.834	10.5	0.406	0.402	0.50	0.367	17.0	0.689	0.697
0.12	-0.752	10.8	0.418	0.420	0.55	0.514	17.8	0.731	0.731
0.14	-0.676	11.3	0.437	0.437	0.60	0.672	18.9	0.770	0.768
0.16	-0.606	11.6	0.449	0.452	0.65	0.842	19.9	0.824	0.809
0.18	-0.539	11.9	0.461	0.466	0.70	1.031	21.3	0.878	0.856
0.20	-0.476	12.4	0.480	0.480	0.75	1.246	22.7	0.968	0.912
0.22	-0.415	12.7	0.491	0.494	0.80	1.500	25.0	1.084	0.981
0.24	-0.356	13.0	0.503	0.507	0.85	1.817	28.0	1.432	1.075
0.26	-0.298	13.3	0.515	0.519	0.90	2.250	37.0	9.800	7.361

n_m = 0.219 mmol g^{-1} n_m(BET) = 0.397 mmol g^{-1} χ_c = -2.676

Table 11 The α-s curve for the data by Bhambhani, Cutting, Sing and Turk referenced to $P/P_{vap} = 0.4$

P/P_{vap}	α-s	α-s fitted	P/P_{vap}	α-s	α-s fitted
0.001	0.258	0.269	0.26	0.858	0.861
0.005	0.348	0.365	0.28	0.877	0.881
0.01	0.400	0.416	0.30	0.897	0.901
0.02	0.497	0.475	0.32	0.916	0.921
0.03	0.548	0.514	0.34	0.935	0.941
0.04	0.581	0.545	0.36	0.955	0.961
0.05	0.600	0.571	0.38	0.974	0.980
0.06	0.606	0.594	0.40	1.000	1.000
0.07	0.626	0.614	0.42	1.006	1.020
0.08	0.645	0.633	0.44	1.039	1.040
0.09	0.658	0.650	0.46	1.058	1.060
0.10	0.677	0.667	0.50	1.097	1.101
0.12	0.697	0.696	0.55	1.148	1.155
0.14	0.729	0.724	0.60	1.219	1.211
0.16	0.748	0.749	0.65	1.284	1.273
0.18	0.768	0.773	0.70	1.374	1.341
0.20	0.800	0.796	0.75	1.465	1.419
0.22	0.819	0.818	0.80	1.613	1.511
0.24	0.839	0.840	0.85	1.806	1.626
0.26	0.858	0.861	0.90	2.387	1.783

Table 12 Data for α-s curves by Payne, Sing and Turk

N_2 Adsortion Data					Ar Adsortion Data				
P/P_{vap}	χ	n_{ads} /mol m^{-2}	n_{ads} mmol g^{-1}	n_{ads} fit	P/P_{vap}	χ	n_{ads} /mol m^{-2}	n_{ads} mmol g^{-1}	n_{ads} fit
0.05	-1.097	34.0	1.518	1.454	0.05	-1.097	23.0	1.027	1.071
0.10	-0.834	38.0	1.696	1.697	0.10	-0.834	29.0	1.295	1.319
0.15	-0.640	43.0	1.920	1.877	0.15	-0.640	32.0	1.429	1.501
0.20	-0.476	46.0	2.054	2.029	0.20	-0.476	38.0	1.696	1.656
0.25	-0.327	48.0	2.143	2.168	0.25	-0.327	41.0	1.830	1.796
0.30	-0.186	51.0	2.277	2.298	0.30	-0.186	43.0	1.920	1.929
0.35	-0.049	54.0	2.411	2.425	0.35	-0.049	45.0	2.009	2.058
0.40	0.087	58.0	2.589	2.551	0.40	0.087	50.0	2.232	2.186
0.45	0.225	58.0	2.589	2.679	0.45	0.225	54.0	2.411	2.316
0.50	0.367	61.0	2.723	2.810	0.50	0.367	55.0	2.455	2.449
0.60	0.672	68.0	3.036	3.093	0.60	0.672	62.0	2.768	2.736
0.70	1.031	77.0	3.437	3.425	0.70	1.031	69.0	3.080	3.075
0.80	1.500	89.0	3.973	3.860	0.80	1.500	79.0	3.527	3.516
0.90	2.250	118.0	5.268	4.555	0.90	2.250	93.0	4.152	4.223
n_m = 0.927 mmol g^{-1} χ_c = -2.666 R = 0.9986					n_m = 0.942 mmol g^{-1} χ_c = -2.235 R = 0.9993				

Table 13 Smoothed α-s curve on silica normalized to $V_{0.4}$ as listed by Gregg and Sing

N_2				Ar			
P/P_{vap}	$V/V_{0.4}$	P/P_{vap}	$V/V_{0.4}$	P/P_{vap}	$V/V_{0.4}$	P/P_{vap}	$V/V_{0.4}$
0.001	0.26	0.280	0.88	0.01	0.243	0.32	0.900
0.005	0.35	0.300	0.90	0.02	0.324	0.34	0.923
0.010	0.40	0.320	0.92	0.03	0.373	0.36	0.948
0.020	0.50	0.340	0.94	0.04	0.413	0.38	0.973
0.030	0.55	0.360	0.96	0.05	0.450	0.40	1.000
0.040	0.58	0.380	0.98	0.06	0.483	0.42	1.022
0.050	0.60	0.400	1.00	0.07	0.514	0.44	1.048
0.060	0.61	0.420	1.01	0.08	0.541	0.46	1.064
0.070	0.63	0.440	0.10	0.09	0.563	0.48	1.098
0.080	0.65	0.460	1.06	0.10	0.583	0.50	1.123
0.090	0.66	0.500	1.10	0.11	0.602	0.50	1.123
0.100	0.68	0.550	1.14	0.12	0.620	0.52	1.148
0.120	0.70	0.600	1.22	0.13	0.638	0.54	1.172
0.140	0.73	0.650	1.29	0.14	0.657	0.56	1.198
0.160	0.75	0.700	1.38	0.15	0.674	0.58	1.225
0.180	0.77	0.750	1.47	0.16	0.689	0.60	1.250
0.200	0.80	0.800	1.62	0.17	0.705	0.62	1.275
0.220	0.82	0.850	1.81	0.18	0.719	0.64	1.300
0.240	0.84	0.900	2.40	0.19	0.733	0.66	1.327
0.260	0.86			0.20	0.748	0.68	1.354
				0.22	0.773	0.70	1.387
				0.24	0.801	0.72	1.418
				0.26	0.826	0.74	1.451
				0.28	0.851	0.76	1.486
				0.30	0.876	0.78	1.527

Table 14 Data and smooth t-curve - N_2 adsorbed on alumina by Lippens, Linsen and deBoer.

t-curve (smoothed data)					original data	
P/P_{vap}	t / Ä	P/P_{vap}	t / Ä		P/P_{vap}	t / Ä
0.08	3.51	0.80	10.57		0.083	3.54
0.10	3.68	0.82	11.17		0.101	3.72
0.12	3.83	0.84	11.89		0.119	3.82
0.14	3.97	0.86	12.75		0.137	3.97
0.16	4.10	0.88	13.82		0.159	4.10
0.18	4.23	0.90	14.94		0.181	4.22
0.20	4.36				0.200	4.38
0.22	4.49				0.227	4.45
0.24	4.62				0.242	4.61
0.26	4.75				0.260	4.72
0.28	4.88				0.285	4.86
0.30	5.01				0.300	5.01
0.32	5.14				0.321	5.14
0.34	5.27				0.339	5.24
0.36	5.41				0.365	5.42
0.38	5.56				0.386	5.55
0.40	5.71				0.408	5.67
0.42	5.86				0.422	5.85
0.44	6.02				0.440	5.98
0.46	6.18				0.458	6.13
0.48	6.34				0.480	6.31
0.50	6.50				0.499	6.44
0.52	6.66				0.520	6.62
0.54	6.82				0.542	6.79
0.56	6.99				0.560	6.97
0.58	7.17				0.579	7.15
0.60	7.36				0.599	7.30
0.62	7.56				0.617	7.51
0.64	7.77				0.635	7.71
0.66	8.02				0.661	7.92
0.68	8.26				0.679	8.22
0.70	8.57				0.700	8.52
0.72	8.91				0.718	8.88
0.74	9.27				0.744	9.24
0.76	9.65				0.758	9.59
0.78	10.07				0.780	10.03

Table 15 Standard isotherm for activated charcoal by RMBM

P/P_{vap}	n/n_m	α-s	P/P_{vap}	n/n_m	α-s	P/P_{vap}	n/n_m	α-s
0.005	0.82	0.51	0.18	1.21	0.76	0.44	1.68	1.05
0.01	0.87	0.54	0.20	1.24	0.78	0.46	1.71	1.07
0.02	0.92	0.58	0.22	1.27	0.79	0.50	1.79	1.12
0.03	0.95	0.59	0.24	1.30	0.81	0.54	1.88	1.18
0.04	0.98	0.61	0.26	1.33	0.83	0.60	2.02	1.26
0.05	1.00	0.63	0.28	1.37	0.86	0.64	2.13	1.33
0.06	1.02	0.64	0.30	1.41	0.88	0.70	2.32	1.45
0.07	1.03	0.64	0.32	1.44	0.90	0.74	2.46	1.54
0.08	1.05	0.66	0.34	1.48	0.93	0.80	2.71	1.69
0.10	1.09	0.68	0.36	1.52	0.95	0.84	2.87	1.79
0.12	1.12	0.70	0.38	1.56	0.98	0.90	3.29	2.06
0.14	1.14	0.71	0.40	1.60	1.00	0.94	3.91	2.44
0.16	1.17	0.73	0.42	1.64	1.03			

Table 16 KFG coefficients for a standard curve extracted from carbons

	coefficients (C_j):					
range	0	1	2	3	4	5
.1-0.6	27.1667	23.449	16.75	6.5135	0.9971	0
.55-.92	46.5644	242.443	1120.65	2884.45	3729.22	1890.9
.90-.99	119.463	4983.14	130098	1.792×10^3	1.2438×10^7	3.4279×10^7

Table 17 α-s curve using coefficients from **Table 16**

P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.1	0.680	0.6	1.219	0.9	1.969
0.2	0.800	0.65	1.287	0.92	2.117
0.3	0.903	0.7	1.374	0.94	2.328
0.4	1.000	0.75	1.471	0.96	2.694
0.5	1.103	0.8	1.582	0.98	3.827
0.6	1.215	0.85	1.734	0.99	5.236
0.55	1.153	0.9	1.977		

Table 18 Standard Nitrogen isotherms of low temperature out-gassed thoria

original data				smoothed α-s curve			
P/P_{vap}	t /Ä	P/P_{vap}	t /Ä	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.016	1.43	0.602	6.93	0.010	0.221	0.300	0.865
0.027	1.72	0.660	7.38	0.020	0.303	0.350	0.933
0.036	2.30	0.701	7.86	0.030	0.351	0.400	1.000
0.078	2.84	0.758	8.38	0.040	0.394	0.450	1.063
0.104	3.17	0.802	9.06	0.050	0.428	0.500	1.135
0.138	3.42	0.848	9.93	0.060	0.457	0.550	1.202
0.205	3.92	0.898	11.22	0.070	0.486	0.600	1.279
0.248	4.39			0.080	0.510	0.650	1.361
0.358	5.07			0.090	0.534	0.700	1.452
0.402	5.36			0.100	0.558	0.750	1.558
0.462	5.72			0.150	0.649	0.800	1.678
0.501	6.13			0.200	0.726	0.850	1.832
0.558	6.42			0.250	0.798	0.900	2.038
χ_c = -1.992		n_m = 2.60 Å or		R = 0.9995			

Table 19 Standard curve to water adsorption of thoria.

original data				smoothed α-s curve			
P/P_{vap}	t /Ä	P/P_{vap}	t /Ä	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.010	0.92	0.535	5.32	0.010	0.169	0.100	0.526
0.048	1.65	0.555	5.62	0.015	0.216	0.150	0.625
0.068	2.48	0.595	6.18	0.020	0.253	0.200	0.710
0.115	2.82	0.655	6.42	0.025	0.283	0.250	0.787
0.152	3.15	0.711	6.85	0.030	0.309	0.300	0.859
0.205	3.34	0.758	7.35	0.035	0.332	0.350	0.930
0.260	3.68	0.795	8.46	0.040	0.353	0.400	1.000
0.321	4.11	0.850	9.32	0.045	0.372	0.450	1.071
0.355	4.85	0.900	10.42	0.050	0.390	0.500	1.144
0.465	5.08			0.055	0.407	0.550	1.220
				0.060	0.422	0.600	1.301
				0.065	0.437	0.650	1.389
				0.070	0.451	0.700	1.486
				0.075	0.465	0.750	1.596
				0.080	0.478	0.800	1.727
				0.085	0.490	0.850	1.891
				0.090	0.503	0.900	2.114
χ_c = -1.855		n_m = 2.45 Å or		R = 0.9996			

Table 20 Argon adsorption on 25°C out-gassed thoria

original data				smoothed α-s			
P/P_{vap}	t /Å	P/P_{vap}	t /Å	P/P_{vap}	t /Å	P/P_{vap}	t /Å
0.011	0.78	0.354	4.94	0.005	0.078	0.650	1.396
0.018	1.13	0.368	5.06	0.010	0.152	0.700	1.496
0.028	1.48	0.378	5.30	0.020	0.238	0.750	1.609
0.038	1.68	0.403	5.32	0.030	0.295	0.800	1.742
0.045	1.86	0.419	5.45	0.040	0.340	0.850	1.909
0.056	2.18	0.444	5.70	0.050	0.378	0.900	2.136
0.064	2.28	0.454	5.75	0.060	0.411		
0.082	2.54	0.468	5.89	0.070	0.440		
0.103	2.81	0.484	5.96	0.080	0.467		
0.118	3.02	0.501	6.18	0.090	0.492		
0.135	3.22	0.520	6.32	0.100	0.516		
0.148	3.30	0.536	6.40	0.150	0.618		
0.158	3.45	0.555	6.52	0.200	0.704		
0.201	3.78	0.561	6.58	0.250	0.782		
0.228	3.94	0.577	6.82	0.300	0.857		
0.235	4.17	0.600	6.96	0.350	0.929		
0.258	4.30	0.652	7.47	0.400	1.000		
0.278	4.46	0.698	7.93	0.450	1.072		
0.302	4.66	0.748	8.55	0.500	1.147		
0.326	4.74	0.802	9.33	0.550	1.224		
0.347	4.88	0.818	9.58	0.600	1.307		
χ_c = -1.816		n_m = 2.81 Å or		R = 0.9994			

Table 21 N_2 adsorption of non-porous lunar soil

original data		smoothed α-s curve			
P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.00051	1.517	0.0005	0.238	0.070	0.616
0.0036	2.357	0.001	0.272	0.080	0.635
0.0069	2.815	0.002	0.310	0.090	0.652
0.013	3.318	0.003	0.335	0.100	0.668
0.027	3.941	0.004	0.353	0.150	0.738
0.054	4.505	0.005	0.368	0.200	0.797
0.106	5.390	0.010	0.418	0.250	0.851
0.159	5.968	0.015	0.451	0.300	0.902
0.211	6.374	0.020	0.477	0.350	0.951
0.267	6.734	0.025	0.498	0.400	1.000
0.319	7.387	0.030	0.516	0.450	1.050
0.382	7.470	0.035	0.533	0.500	1.101
0.419	7.395	0.040	0.547	0.550	1.154
0.464	7.770	0.050	0.573		

Table 22 Argon adsorption on non-porous lunar soil

original data				smoothed α-s curve			
P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.029	2.327	0.411	6.869	0.020	0.361	0.400	1.000
0.059	3.416	0.500	7.583	0.040	0.447	0.450	1.061
0.099	3.949	0.600	8.483	0.060	0.507	0.500	1.123
0.144	4.557	0.691	9.234	0.080	0.554	0.550	1.188
0.198	5.210	0.766	10.248	0.100	0.595	0.600	1.257
0.253	5.676			0.150	0.680	0.650	1.332
0.306	6.096			0.200	0.752	0.700	1.415
0.355	6.517			0.250	0.818	0.750	1.510
				0.300	0.880	0.800	1.621
				0.350	0.940		

Table 23 Adsorption of O_2 on non-porous lunar soil

original data				smoothed α-s curve			
P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.0003	0.000	0.245	4.880	0.00380	0.000	0.100	0.490
0.0006	0.000	0.280	5.631	0.004	0.0051	0.150	0.597
0.0014	0.000	0.352	6.246	0.005	0.028	0.200	0.688
0.0033	0.038	0.397	6.682	0.010	0.106	0.250	0.771
0.0117	0.788	0.452	7.222	0.015	0.157	0.300	0.849
0.0335	1.567	0.523	7.770	0.020	0.196	0.350	0.925
0.065	2.477	0.575	8.281	0.025	0.229	0.400	1.000
0.099	3.078	0.644	8.926	0.030	0.257	0.450	1.076
0.132	3.491	0.713	9.857	0.035	0.282	0.500	1.155
0.161	3.911			0.040	0.304	0.550	1.237
				0.050	0.344	0.600	1.324
				0.060	0.379	0.650	1.418
				0.070	0.410	0.700	1.523
				0.080	0.438	0.750	1.642
				0.090	0.465		

Table 24 CO adsorption on non-porous lunar soil

original data				smoothed α-s curve			
P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	n_{ads} /μmol g^{-1}	P/P_{vap}	$n/n_{0.4}$	P/P_{vap}	$n/n_{0.4}$
0.0006	2.793	0.219	7.583	0.0005	0.304	0.050	0.610
0.0031	3.378	0.274	8.071	0.001	0.335	0.100	0.697
0.0114	4.204	0.324	8.521	0.002	0.370	0.150	0.760
0.0215	4.557	0.389	8.694	0.003	0.392	0.200	0.815
0.0460	5.541	0.425	9.047	0.004	0.409	0.250	0.864
0.0854	6.119	0.484	9.497	0.005	0.422	0.300	0.910
0.133	6.607	0.538	9.970	0.010	0.469	0.350	0.955
0.177	7.132			0.015	0.499	0.400	1.000
				0.020	0.522	0.450	1.045
				0.025	0.542	0.500	1.092
				0.030	0.558	0.550	1.141
				0.035	0.573	0.600	1.192
				0.040	0.586	0.650	1.248

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