

ANALITIČNI IZRAZ ZA ČEMOV DALJKI

$$a_{1761} = \alpha_r e^{-d_{sr} d} (1 - \alpha_{sr} e^{-d_{sr} d})$$

$$\left. a_{1761} \right|_{d=0} = \alpha_r (1 - \alpha_{sr})$$

$$\frac{\partial a_{1761}}{\partial d} = \alpha_{er} (\alpha_r) e^{-d_{sr} d} (1 - \alpha_{sr} e^{-d_{sr} d}) + \alpha_{er} e^{-d_{sr} d} (-1) \alpha_{sr} (-d_{sr}) e^{-d_{sr} d}$$

$$\left. \frac{\partial a_{1761}}{\partial d} \right|_{d=0} = -\alpha_{er} \alpha_r (1 - \alpha_{sr}) + \alpha_{er} \alpha_{sr} d_{sr} = \text{Slope}(0)$$

$$\frac{\partial^2 a_{1761}}{\partial d^2} = 0 \Rightarrow \cancel{\alpha_{er} \alpha_r e^{-d_{sr} d} (1 - \alpha_{sr} e^{-d_{sr} d})} = \cancel{\alpha_{er} e^{-d_{sr} d} \alpha_{sr} e^{-d_{sr} d} \alpha_{sr} e^{-d_{sr} d}}$$

$$\cancel{\alpha_{sr} e^{-d_{sr} d}} = \alpha_{sr} d_{sr} e^{-d_{sr} d}$$

$$\frac{a_{1761}^0}{\alpha_{er} e^{-d_{sr} d_0} \cdot \cancel{\alpha_{sr}}} = \alpha_{sr} d_{sr} e^{-d_{sr} d_0}$$

$$a_{1761}^0 = \alpha_{sr} \alpha_{er} \frac{d_{sr}}{\alpha_{er}} e^{-(\alpha_{sr} + \alpha_{er}) d_0}$$

$$a_{1761}^0 = e^{-(\alpha_{sr} + \alpha_{er}) d_0} \cdot \left(\frac{\text{Slope}(0)}{\alpha_{er}} + \alpha_{er} (1 - \alpha_{sr}) \right) =$$

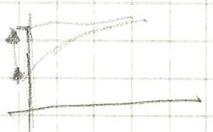
$$\left. a_{1761} \right|_{d=0} = \alpha_{er} (1 - \alpha_{sr}) = e^{-(\alpha_{sr} + \alpha_{er}) d_0} \left(\frac{\text{Slope}(0)}{\alpha_{er}} + \left. a_{1761} \right|_{d=0} \right)$$

$$1 - \alpha_{sr} e^{-d_{sr} d_0} = \alpha_{sr} \frac{d_{sr}}{\alpha_{er}} e^{-d_{sr} d_0}$$

$$\alpha_{sr} \left(1 + \frac{d_{sr}}{\alpha_{er}} \right) e^{-d_{sr} d_0} = 1$$

$$\alpha_{sr} = 1 - \frac{a_{1761}^0}{\alpha_{er}}$$

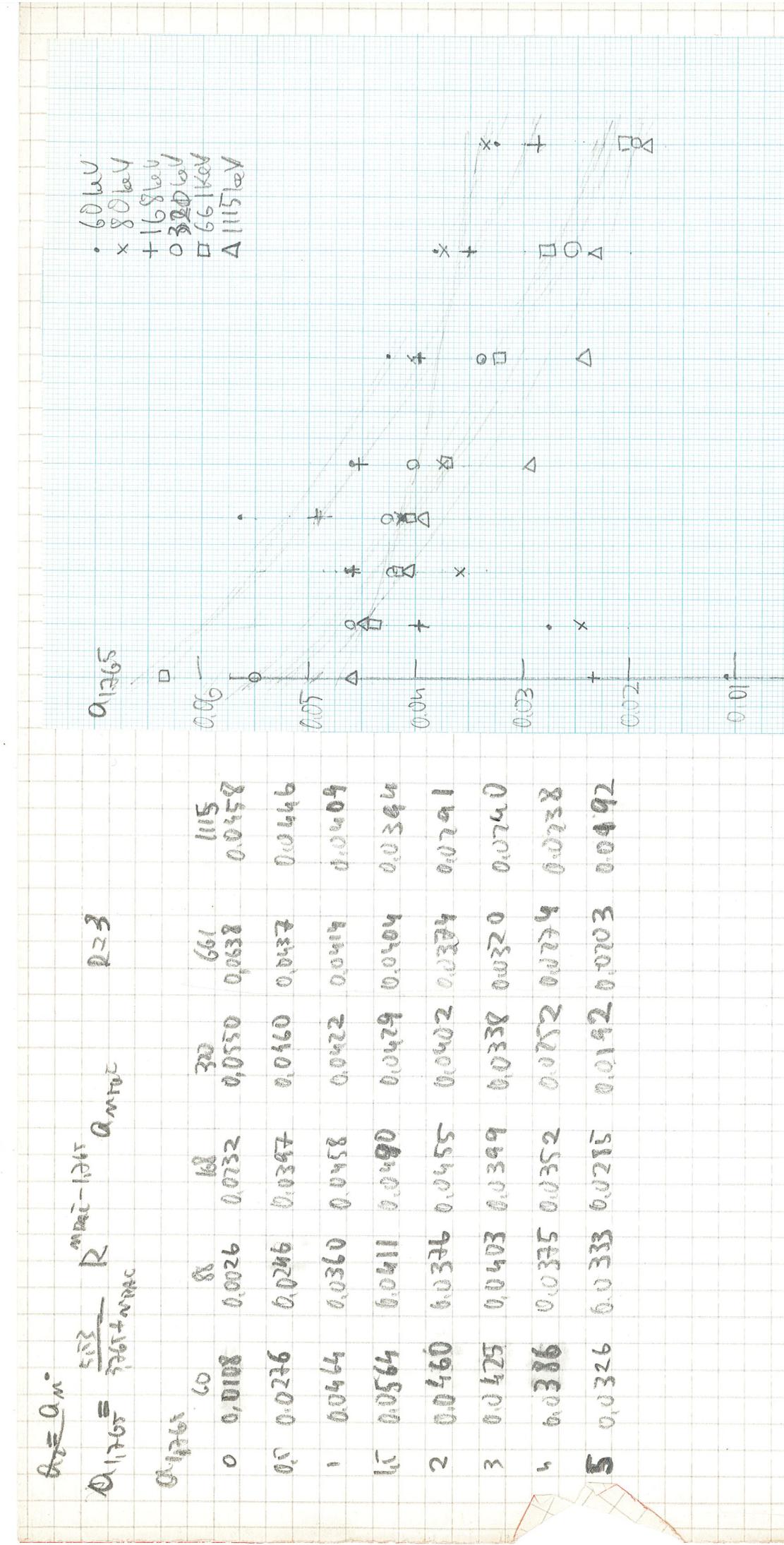
$$\alpha_{sr} = e^{d_{sr} d_0} / \left(1 + \frac{d_{sr}}{\alpha_{er}} \right)$$



6) KOD PREDVU?

✓
✓
✓
✓

E	0.20	0.20ESR	0.20EXSR	SL
60	0.065	0.144	0.13	0.028
88	0.067	0.140	0.13	0.025
168	0.066	0.146	0.135	0.023
320	0.052	0.139		
661	0.055	0.166		
1115	0.049	0.179		



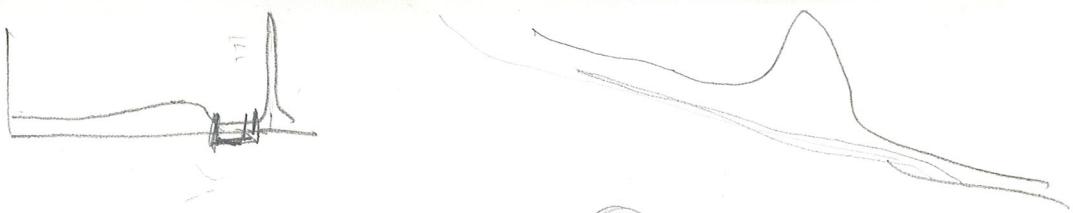
八
三

10

卷之三

	d_{11}	d_{12}	d_{13}	d_{14}
30	0.12	0.12	0.12	0.12
40	0.125	0.125	0.125	0.125
50	0.135	0.135	0.135	0.135
60	0.14	0.14	0.14	0.14
70	0.145	0.145	0.145	0.145
80	0.15	0.15	0.15	0.15
100	0.16	0.16	0.16	0.16
120	0.165	0.165	0.165	0.165
140	0.17	0.17	0.17	0.17
160	0.172	0.172	0.172	0.172
180	0.175	0.175	0.175	0.175
200	0.178	0.178	0.178	0.178
250	0.18	0.18	0.18	0.18
300	0.182	0.182	0.182	0.182
400	0.185	0.185	0.185	0.185
500	0.187	0.187	0.187	0.187
700	0.188	0.188	0.188	0.188
1000	0.188	0.188	0.188	0.188
2000	0.187	0.187	0.187	0.187
3000	0.186	0.186	0.186	0.186

1)



$$N_1 = \frac{ob \cdot \epsilon}{unit} e^{-\mu(E)d}$$

N

↓

2)



$$N_1 = \frac{ob \cdot \epsilon}{unit} e^{-\mu(E)d}$$

$$\mu_2 = \frac{ob \cdot \epsilon}{unit} e^{-\mu(E)d}$$

$$\text{And } d = \ln \frac{N_1}{N_2}$$

PK	NUCLIDE	ENERGY	HLFE	DECAY	HQ	UNIT	%
4	I-131	80.20	8.020	1. 555E-1			
17	RA-228	209.40	6.70Y	1. 002E-0	7. 764E-5		
20	PB-214	242.00	100.00Y	1. 001E-0	6. 921E-4		4
24	PB-214	225.40	100.00Y	1. 001E-0	7. 557E-6		4
47	BA-140	537.30	12.750	3. 624E-0	1. 210E-5		72
61	BIA-214	609.20	100.00Y	1. 001E-0	1. 065E-5		67
65	SB-125	605.90	2.72Y	1. 022E-0	4. 105E-5		16.4
66	I-131	637.00	9.020	1. 555E-1	8. 605E-4		10.9
73	TE-129m	695.90	33.600	1. 927E-0	7. 684E-5		30.9%
79	ZR-95	756.70	64.000	1. 411E-0	2. 665E-6		55.9%
85	LA-140	815.80	14.500	4. 567E-0	1. 325E-4		12.72%
110	FB-59	1009.00	44.500	1. 641E-0	3. 046E-6		56.73%
122	BIA-214	1238.10	100.00Y	1. 001E-0	2. 094E-5		67.52%
132	BIB-214	1377.60	100.00Y	1. 001E-0	6. 549E-5		15.67%
133	AG-110M	1384.30	242.900	1. 092E-0	4. 405E-6		11.85%

LINES NOT MEETING SUMMARY CRITERIA

PK	NUCLIDE	ENERGY	HLFE	DECAY	HQ	UNIT	%
4	I-131	80.20	8.020	1. 555E-1			
17	RA-228	209.40	6.70Y	1. 002E-0	7. 764E-5		
20	PB-214	242.00	100.00Y	1. 001E-0	6. 921E-4		4
24	PB-214	225.40	100.00Y	1. 001E-0	7. 557E-6		4
47	BA-140	537.30	12.750	3. 624E-0	1. 210E-5		72
61	BIA-214	609.20	100.00Y	1. 001E-0	1. 065E-5		67
65	SB-125	605.90	2.72Y	1. 022E-0	4. 105E-5		16.4
66	I-131	637.00	9.020	1. 555E-1	8. 605E-4		10.9
73	TE-129m	695.90	33.600	1. 927E-0	7. 684E-5		30.9%
79	ZR-95	756.70	64.000	1. 411E-0	2. 665E-6		55.9%
85	LA-140	815.80	14.500	4. 567E-0	1. 325E-4		12.72%
110	FB-59	1009.00	44.500	1. 641E-0	3. 046E-6		56.73%
122	BIA-214	1238.10	100.00Y	1. 001E-0	2. 094E-5		67.52%
132	BIB-214	1377.60	100.00Y	1. 001E-0	6. 549E-5		15.67%
133	AG-110M	1384.30	242.900	1. 092E-0	4. 405E-6		11.85%

Assuming only single scattering and neglecting the response of the spectrometer in the energy interval ΔE to the gamma rays of energy E , the count rate in the energy interval $\Delta E = [E_1, E_2]$ can be expressed [2] as:

$$n_C(\Delta E, E) = n_B(\Delta E) + K(\Delta E, E) \mu(E) s n(E) \quad (3)$$

where $n_B(\Delta E)$ denotes the count rate in the absence of the source and $K(\Delta E, E)$ the probability of scattering into the energy interval ΔE , when any interaction takes place:

$$K(\Delta E, E) = \frac{\int_{\theta_1(E_1)}^{\theta_2(E_2)} \sigma_{KN}(\theta, E) d\Omega(\theta)}{\sigma_{tot}(E)} \quad (4)$$

Here θ denotes the scattering angle, $\sigma_{tot}(E)$ the total cross section and $\sigma_{KN}(\theta, E)$ the Klein-Nishina cross section. The interval of integration over the scattering angles is defined by the energy interval ΔE . The attenuation of photons can be calculated from the count rates $n_C(\Delta E, E)$ and $n'_C(\Delta E, E)$ in the energy interval ΔE measured at the distances d and d' by eliminating the background count rate $n_B(\Delta E)$:

$$\mu(E) s = \frac{1}{K(\Delta E, E)} \frac{n'_C(\Delta E, E) - n_C(\Delta E, E)}{n'(E) - n(E)} \quad (5)$$

In this way the attenuation factor can be calculated and the activity also determined for single line gamma-ray emitters.

3. Experiment

The validity of the described approach was tested by performing measurements with the radioisotope ^{65}Zn with a source ZN65-ELSB50, calibrated with accuracy of 2%, and purchased from CEA, France. The measurements were performed with a layer of material interposed between the source and the detector. The material consisted of a 40 cm thick layer of sand with a density of 1.81. The spectrum was measured with an n-type semiconductor detector, of relative efficiency 24% and resolution 2.0 keV at 1333 keV at distances of 0.5 and 1 m from the side of the layer facing the detector. The accuracy of the positioning was 0.1 cm. The total count rate in the spectra attained approximately 200 and 300 cps and the measurements lasted 0.5 and 1.5 hours, respectively. The energy interval ΔE where the contribution of scattered rays to the spectrum was measured spanned from 1038 to 1090 keV. The probability for scattering to that energy interval was 0.053, assuming silicon dioxide as the chemical composition of the sand. The total cross section and the mass attenuation coefficients were obtained from [3]. Table 1 presents the reference values of the quantities calculated from the spectral data and their measured values.

Table 1. Comparison of reference values of quantities with their measured values determined from the spectral data.

	Reference value	Calculated value
d [cm]	97	96 ± 2
$\mu(1115 \text{ keV}) s$	4.4	4.7 ± 0.4
Activity [MBq]	44.9 ± 0.9	75 ± 30

4. Discussion and conclusion

The activity of a remote source can be calculated on the basis of the detector calibration if the distance between the source and the detector, as well as the attenuation factor are known. Two measurements are necessary to determine the distance. It has been shown that the attenuation factor can be obtained from the same two measurements by measuring the amount of the radiation scattered for small angles

MEASUREMENT OF THE ACTIVITY OF A REMOTE SOURCE BY IN-SITU GAMMA-RAY SPECTROMETRY

M. Korun, D. Glavič-Cindro, R. Martinčič, B. Pucelj and T. Vidmar

Jožef Stefan Institute, 1000 Ljubljana, Jamova 39, Slovenia

Abstract: A method for calculation of the attenuation factor for gamma rays passing through a layer of material is presented. The method is based on the measurement of the amount of radiation scattered in the material at small angles and registered in the spectra of a high resolution gamma-ray detector. The method is applied to the calculation of the activity of a remote source. The attenuation factor, the distance between the source and detector as, well as the activity of the source were calculated from the spectra and compared to their reference values.

1. Introduction

In recent years in-situ gamma-ray has become a powerful tool in the field of on-site radiation measurements. The use of energy dispersive spectrometers for location of gamma-ray sources is advantageous with respect to counters, since the unattenuated fraction of the photons is registered in the spectrum at different energies from the photons scattered in the materials between the source and the detector. To calculate the activity of the source, its distance from the detector and the fraction of photons attenuated in the material between the source and the detector must be known. The distance between the source and the detector can be calculated from the count rates in the full energy peaks in the spectra measured at different distances, utilizing the inverse square law. For sources emitting photons at different energies, the amount of material between the source and the detector can be calculated on the basis of the different attenuation of gamma rays at different energies. For sources radiating photons at just one energy (e.g. ^{137}Cs , ^{65}Zn , etc.) a method based on the measurement of the radiation scattered at small angles was developed.

2. Theory

The count rate in the full energy peak of a source emitting gamma rays at energy E can be expressed by its activity a , the emission probability b , the distance d , and the efficiency of the spectrometer ε as

$$n(E) = \frac{ab\varepsilon}{4\pi d^2} e^{-\mu(E)s} \quad (1)$$

where $\mu(E)$ and s denote the attenuation coefficient and the thickness of the material placed between the detector and the source. The distance d can be calculated from that count rate and the count rate $n'(E)$, measured at the distance $d' = d + d_0$:

$$d = d_0 \left(\sqrt{\frac{n(E)}{n'(E)}} - 1 \right)^{-1} \quad (2)$$

The activity of the source can be calculated only if the efficiency ε and the attenuation factor $e^{-\mu(E)s}$ are known. The latter can be calculated from the amount of radiation scattered in the material between the source and the detector at small angles.

The passage of photons through material is accompanied by Compton scattering. The energy lost in a scattering event is connected with the scattering angle [1]; scattering at small angles is connected with small energy losses. The energy interval ΔE suitable for measuring the amount of scattered radiation must lie close to the full energy peak in region where the response of the spectrometer to unscattered gamma rays has its minimum.

Exercise No. 1: In situ measurements over an area with heterogenous

distribution of ^{226}Ra in the soil

page 1

V V
NCIC
2891

uniform

N	unit mass (kg)	3.3	33.1 ± 1.1
0.56	1.9	3.3	33.1 ± 1.1
0.87	6.3	3.3	32.9 ± 1.1
	3.8	3.3	32.9 ± 1.1
	5	5	18.2 ± 2
	± 2.3	± 2.3	18.2 ± 2
	± 1.5	± 1.5	18.2 ± 2
	583	0.19	21.0 ± 1.9
^{202}Tl	2615	0.12	20.0 ± 1.2
			20.3 ± 1.2

D
70 72596 34%
60 14345 5.6%
sum 1 10416% 77105
1.108 ± 5.0

in the material interposed between the source and the detector. The amount of radiation scattered is given by the increase of the count rate in the energy interval ΔE over the background count rate, attained in the absence of the source. The uncertainty of this increase is the main source of uncertainty which determines the accuracy of the calculated activity. Therefore care must be taken to avoid systematic errors, such as registration of pulses deformed by the pile-up effect and the contribution of the rate-dependent low-energy tail of the full energy peak to the count rate in the energy interval ΔE .

The method is useful in the case when the source emits gamma rays at just one energy and the calculation of the attenuation factor cannot be performed on the basis of the energy dependence of the attenuation coefficients. It has been shown that it yields useful results in the case when the contribution of the scattered radiation can be reliably estimated.

5. References

1. K. Debertin and R. G. Helmer, Gamma- and X-Ray Spectrometry with Semiconductor Detectors (North-Holland, Amsterdam, 1988).
2. M. Korun, Submitted for publication in NIM.
3. J. H. Hubbel, Photon Cross Sections, Attenuation Coefficients and Energy Absorption Coefficients from 10 keV to 100 GeV, NSRDS-NBS 29, (1969).

E	$\mu(\text{H}_2\text{O})/\text{cm}^2(\text{g})$
352	0.112
604	0.0895
1220	0.0674
1765	0.0534
2208	0.0474
2468	0.0445

faint 1

C₀ + 137

$$a_0 = 0.0264 \pm 0.001 \text{ Bg/cm}^3$$

$$d = 3.37 \pm 0.02 \text{ cm}$$

$$\text{deposit: } 890 \pm 40 \text{ Bg/m}^2$$

	2=1	2=2	4	8
E ₀	1115	1115	1115	1115
E ₁₂	1038	1038	1038	1038
E ₂₂	1090	1090	1090	1090
Light	1.004 \cdot 10^{-2}	7.004 \cdot 10^{-2}	0.146	0.0135
Computer	0.200	4.0017	7.80	1.000
Top	0.0501		0.052	0.052

$$N_2 = ab\eta e^{-pd_1} = ab \frac{s}{\pi d_1^2} e^{-pd_1} = ab \frac{\eta \pi d_1^2 \text{ cm}^2}{\pi d_1^2} e^{-pd_1} = ab\eta \frac{4\pi}{d_1^2} e^{-pd_1}$$

$$\geq ab\eta (\bar{s}) \left(\frac{4\pi}{d}\right)^2 e^{-pd_1}$$

$$\alpha = \frac{i}{D\eta(\bar{s}) \left(\frac{4\pi}{d}\right)^2} e^{-pd_1}$$