NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL, MINING & PROCESS ENGINEERING

QUALIFICATION(S): BACHELOR OF ENGINEERING IN METALLURGY & CHEMICAL ENGINEERING	
QUALIFICATION CODE: 08BEMT & 08BECE	LEVEL: 7
COURSE CODE: ETP720S	COURSE NAME: EXPERIMENTAL TECHNIQUES FOR PROCESS ENGINEERS 324
SESSION: NOVEMBER 2022	PAPER: THEORY
DURATION: 3 HOURS	MARKS: 100

SECOND OPPORTUNITY QUESTION PAPER	
EXAMINER:	MR. THOMAS MOONGO
MODERATOR:	PROF. JONAS ADDAI-MENSAH

INSTRUCTIONS

1. Answer all questions.
2. Read all the questions carefully before answering.
3. Marks for each questions are indicated at the end of each question.
4. Please ensure that your writing is legible, neat, and presentable.

PERMISSIBLE MATERIALS

1. Examination paper.
2. Calculator and stationary.

THIS QUESTION PAPER CONSISTS OF 9 PAGES (Including this front page)

SECTION A [30 marks]

Question 1 **[5 marks]**

Create an appropriate flow sheet to illustrate logically sequenced steps of the experiment process. At least five (5) experiment process steps should be considered.

Question 2 **[5 marks]**

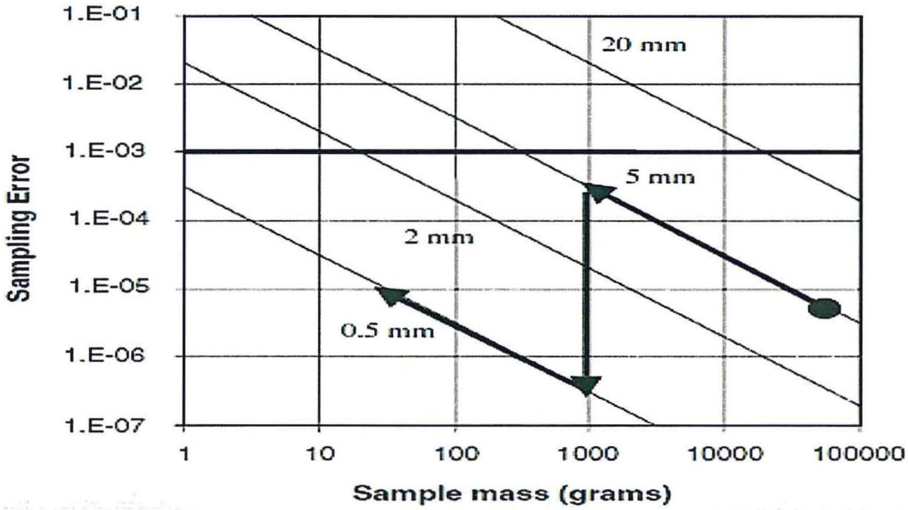
What is a fractional factorial design? Explain the main use and experiments for which you will consider utilizing fractional factorial design.

Question 3 **[5 marks]**

Justify why randomization is critical in the design of experiments (DOE).

Question 4 **[5 marks]**

Sampling nomographs are useful during the execution of experiments. Discuss the application of a nomograph for preparing a gold sample as shown below by explaining the sampling steps and quantities (in terms of sampling error and sample mass) involved here.

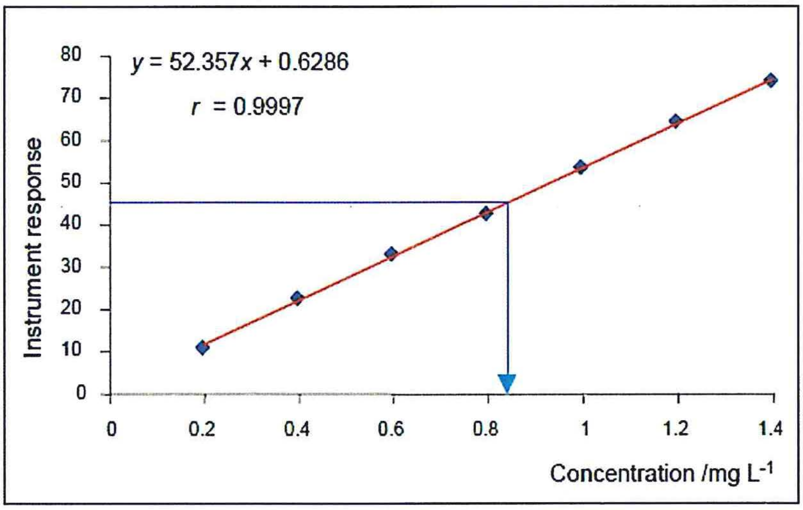


Question 5 **[5 marks]**

Discuss the application of the Beer-Lambert equation/law when conducting process engineering experiments.

Question 6 **[5 marks]**

With reference to the below graph, explain how the calibration curve is created and applied during the experimentation process especially when it comes to the chemical analysis of samples.


y = 52.357x + 0.6286
r = 0.9997
Instrument response
Concentration /mg L-1
0
10
20
30
40
50
60
70
80
0.2
0.4
0.6
0.8
1
1.2
1.4

SECTION B **[70 marks]**

Question 1 **[10 marks]**

Process engineers are conducting experiments in the oil and gas industry for the recently discovered oil in Namibia. A 2^3 full factorial experiment was carried out to understand the interaction between factor A and B. Calculate the interaction between factor A and B. In addition to that use the graphical method to illustrate if there is an interaction between factor A and B.

Run (standard order)	Run (randomized order)	A	B	C	Response (ppm)
1	5	-1	-1	-1	420, 412
2	7	+1	-1	-1	370, 375
3	4	-1	+1	-1	310, 289
4	1	+1	+1	-1	410, 415
5	8	-1	-1	+1	375, 388
6	3	+1	-1	+1	450, 442
7	2	-1	+1	+1	325, 322
8	6	+1	+1	+1	350, 340

Question 2 **[10 marks]**

The table below show experimental data obtained from Ohorongo Cement in Namibia.

324	401	203	458	156
253	159	318	376	376
313	189	524	362	413

Answer the following questions:

(a) Determine the measures of central tendency using the given data. [3 marks]

(b) Compute the measures of spread using the given data. [7 marks]

Question 3 **[10 marks]**

As part of ensuring a safe working environment Dundee Precious Metal Tsumeb smelter is applying the vitrification process to create glass products from arsenic wastes. Experiments were conducted and the data is shown below. Calculate the 95% confidence interval about the mean.

16.968 16.922 16.840 16.883

16.887 16.977 16.857 16.728

Question 4 **[10 marks]**

A chemical engineering company management believes that the average cost for atomic absorption spectroscopy (AAS) analysis is N$175 per sample. To test this belief, the chemical engineering company management conducted a survey among a random sample of 360 laboratories. Based on the survey, the average cost for AAS analysis was N$182.40 per sample. Assuming that the population of AAS analysis cost is normally distributed with a standard deviation, σ, of N$67.50.

Can the chemical engineering company management conclude that the AAS analysis cost N$175 per sample, on average? Conduct a test at the 5% level of significance. Clearly show all the steps, illustration sketch and interpolate if necessary.

Question 5 **[10 marks]**

Namib Lead and Zinc Mine is considering undertaking experiments to improve process efficiencies. First, they are considering determining the minimum quantity of a sample required for metallurgical testwork for a lead ore assaying 5% Pb which must be routinely sampled for assay to a confidence level of $\pm$0.1% Pb, 95 times out of 100. Galena is essentially liberated from the quartz gangue at a particle size of 150μm. Assume that the sample will be collected during crushing to a top size of 25 mm. The mean density of Galena and Quartz is 7.50 g/cm^3 and 2.65 g/cm^3.

Question 6 **[20 marks]**

Experiments conducted for the design of a nuclear reactor in Namibia resulted in the data given in the table below. Use the data to answer the following questions:

x	4	4	3	2	5	2	4	3	5	5	3	4
y	26	28	24	18	35	24	36	25	31	37	30	32

(a) Determine the value of variable y when x = 7 and calculate Pearson's correlation coefficient by using the appropriate formula. *[10 marks]*

(b) At the 5% level of significance, test whether the population correlation coefficient, ρ, between variable x and y is actually zero. Clearly show all your steps and draw a sketch using an appropriate statistical testing method for the correlation coefficient. *[10 marks]*

List of Equations

t-crit = $t_{(\alpha,n-1)}$

Range = $X_{largest}$ - $X_{smallest}$

C = fg$l$m

$I_{A,B} = \frac{1}{2}\left(E_{A,B(+1)} - E_{A,B(-1)}\right)$

y = $b_0 + b_1$x

z-stat = $\frac{\bar{x} - \mu}{\frac{\sigma}{\sqrt{n}}}$

t-stat = r$\sqrt{\frac{(n-2)}{1-r^2}}$

$\sigma_x = \frac{\sigma}{\sqrt{n}}$

r = $\frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2]\times[n\sum y^2 - (\sum y)^2]}}$

$\sigma^2 = \frac{1}{N}\sum(x - \mu)^2$

E = Z$\times\frac{\sigma}{\sqrt{n}}$

M = $\frac{Cd^3}{s^2}$

$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$

t-stat = $\frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$

$b_1 = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$

$\bar{x} = \frac{\sum_{i=1}^{n} X_i}{n}$

S = $\sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$

m = $\frac{1-a}{a}[(1-a)r + at]$

$b_0 = \frac{\sum y - b_1 \sum x}{n}$

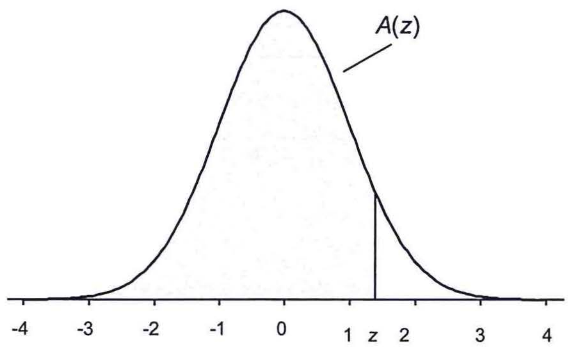
$S^2 = \frac{1}{n-1}\sum(x - \bar{x})^2$

STATISTICAL TABLES

TABLE A.1

Cumulative Standardized Normal Distribution

$A(z)$ is the integral of the standardized normal distribution from $-\infty$ to z (in other words, the area under the curve to the left of z). It gives theprobability of a normal random variable not being more than z standard deviations above its mean. Values of z of particular importance:



z	$A(z)$	
1.645	0.9500	Lower limit of right 5% tail
1.960	0.9750	Lower limit of right 2.5% tail
2.326	0.9900	Lower limit of right 1% tail
2.576	0.9950	Lower limit of right 0.5% tail
3.090	0.9990	Lower limit of right 0.1% tail
3.291	0.9995	Lower limit of right 0.05% tail

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998
3.5	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
3.6	0.9998	0.9998	0.9999							

TABLE A.2
t Distribution: Critical Values of *t*

Degrees of freedom		Significance level					
	Two-tailed test:	10%	5%	2%	1%	0.2%	0.1%
	One-tailed test:	5%	2.5%	1%	0.5%	0.1%	0.05%
1		6.314	12.706	31.821	63.657	318.309	636.619
2		2.920	4.303	6.965	9.925	22.327	31.599
3		2.353	3.182	4.541	5.841	10.215	12.924
4		2.132	2.776	3.747	4.604	7.173	8.610
5		2.015	2.571	3.365	4.032	5.893	6.869
6		1.943	2.447	3.143	3.707	5.208	5.959
7		1.894	2.365	2.998	3.499	4.785	5.408
8		1.860	2.306	2.896	3.355	4.501	5.041
9		1.833	2.262	2.821	3.250	4.297	4.781
10		1.812	2.228	2.764	3.169	4.144	4.587
11		1.796	2.201	2.718	3.106	4.025	4.437
12		1.782	2.179	2.681	3.055	3.930	4.318
13		1.771	2.160	2.650	3.012	3.852	4.221
14		1.761	2.145	2.624	2.977	3.787	4.140
15		1.753	2.131	2.602	2.947	3.733	4.073
16		1.746	2.120	2.583	2.921	3.686	4.015
17		1.740	2.110	2.567	2.898	3.646	3.965
18		1.734	2.101	2.552	2.878	3.610	3.922
19		1.729	2.093	2.539	2.861	3.579	3.883
20		1.725	2.086	2.528	2.845	3.552	3.850
21		1.721	2.080	2.518	2.831	3.527	3.819
22		1.717	2.074	2.508	2.819	3.505	3.792
23		1.714	2.069	2.500	2.807	3.485	3.768
24		1.711	2.064	2.492	2.797	3.467	3.745
25		1.708	2.060	2.485	2.787	3.450	3.725
26		1.706	2.056	2.479	2.779	3.435	3.707
27		1.703	2.052	2.473	2.771	3.421	3.690
28		1.701	2.048	2.467	2.763	3.408	3.674
29		1.699	2.045	2.462	2.756	3.396	3.659
30		1.697	2.042	2.457	2.750	3.385	3.646
32		1.694	2.037	2.449	2.738	3.365	3.622
34		1.691	2.032	2.441	2.728	3.348	3.601
36		1.688	2.028	2.434	2.719	3.333	3.582
38		1.686	2.024	2.429	2.712	3.319	3.566
40		1.684	2.021	2.423	2.704	3.307	3.551
42		1.682	2.018	2.418	2.698	3.296	3.538
44		1.680	2.015	2.414	2.692	3.286	3.526
46		1.679	2.013	2.410	2.687	3.277	3.515
48		1.677	2.011	2.407	2.682	3.269	3.505
50		1.676	2.009	2.403	2.678	3.261	3.496
60		1.671	2.000	2.390	2.660	3.232	3.460
70		1.667	1.994	2.381	2.648	3.211	3.435
80		1.664	1.990	2.374	2.639	3.195	3.416
90		1.662	1.987	2.368	2.632	3.183	3.402
100		1.660	1.984	2.364	2.626	3.174	3.390
120		1.658	1.980	2.358	2.617	3.160	3.373
150		1.655	1.976	2.351	2.609	3.145	3.357
200		1.653	1.972	2.345	2.601	3.131	3.340
300		1.650	1.968	2.339	2.592	3.118	3.323
400		1.649	1.966	2.336	2.588	3.111	3.315
500		1.648	1.965	2.334	2.586	3.107	3.310
600		1.647	1.964	2.333	2.584	3.104	3.307
∞		1.645	1.960	2.326	2.576	3.090	3.291

PERIODIC TABLE OF ELEMENTS

Atomic #
Symbol
Name
Weight

- C Solid
- Hg Liquid
- H Gas
- Rf Unknown

Metals: Alkali metals | Alkaline earth metals | Lanthanoids (Lanthanides) | Actinoids (Actinides) | Transition metals | Post-transition metals

Metalloids

Nonmetals: Other nonmetals | Noble gases

Pnictogens (15) | Chalcogens (16) | Halogens (17)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.008																	2 He Helium 4.0026
2	3 Li Lithium 6.94	4 Be Beryllium 9.0122											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminium 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
4	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
6	55 Cs Caesium 132.91	56 Ba Barium 137.33	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

6	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97
7	89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (266)

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THE END