كشف وقياس الإشعاع (أشعة جاما وجسيمات ألفا وبيتا)

أ. أسماء سعيد أبوعجيلة المهدي - كلية العلوم العجيلات – جامعة الزاوية

ملخص الدراسة:

هذه الدراسة البحثية تتناول الطرق والوسائل المختلفة للكشف عن الإشعاع المؤين (أشعة جاما وجسيمات بيتا وجسيمات ألفا) وقياسه من خلال خصائص التفاعل مع مادة الكاشف التي سوف يتم استخدامها و أيضًا يتم اختيار نوع الكاشف بشكل عام حسب نوع الإشعاع على سبيل المثال إذا كان الإشعاع المكون من شعاع من الفوتونات هنا من الأفضل استخدام مكشاف أشباه الموصلات، ومن أجل جسيمات ألفا أو بيتا يمكننا استخدام عداد مولدات غايغر .

وعند مرور الإشعاع المؤين عبر الكاشف فيؤدي إلى تبدد الطاقة من خلال موجة من التأين ,ويتم تحويل هذا الاندفاع التأين إلى نبضة كهربائية تعمل على تشغيل جهاز القراءة ، مثل مقياس رقمي أو عداد معدل ، لتسجيل عدد من القراءات.

وأيضا سوف نتطرق الي فهم طبيعة النشاط الإشعاعي وكيفية عمل أجهزة الكشف ودور كل مكون من مكونات نظام الكشف المعني ، وسوف نلاحظ أن هناك العديد من العوامل التي تؤثر على نتيجة القياس والكشف الإشعاعي المؤين لأشعة جاما ، وجسيمات بيتا وألفا .

Detection and Measurement of Radiation (gamma rays, beta and alpha particles)

A.Asma saeed Abogila Elmahdi
faculty of Science- El Ajelat , Zawia University

Abstract:

In this work we will introduce the various ways and means of detecting and measuring ionizing radiation, through its

interaction attributes with the material of the detector that will be used, also the type of detector generally is chosen due the type of the radiation for example for the radiation consist of beam of photons it is better to use semiconductor detectors and for alpha or beta we can use the Geiger- Muller counter even for low energies.

This work is focusing into detection and measurement of gamma rays, beta and alpha particles. In all cases, the passage of an ionizing radiation through the detector results in energy dissipation through a burst of ionization. This burst of ionization is converted into an electrical pulse that actuates a readout device, such as a scalar or a rate-meter, to register a count. It is necessary to understand the nature of radioactivity and how the detectors work and the role of each component of detection system involved. Also we will see there are several factors affecting the measurement result of ionizing radiation detection of gamma rays, beta and alpha particles in this experiment.(keywords)

1.0 Introduction:

All substance are made of atoms. These have electrons (e) around the outside, and a nucleus in the middle. The nucleus consists of protons (p) and neutrons (n), and is extremely small. (Atoms are almost entirely made of empty space!). In some types of atom, the nucleus is unstable, and will decay into a more stable atom. This radioactive decay is completely spontaneous. You can heat the substance up, or subject it to high pressure or strong magnetic fields - in fact, do whatever you like to it - and you won't affect the rate of decay in the slightest. When an unstable nucleus decays, there are three ways that it can do so. It may give out:-

- an alpha particle (we use the symbol α)
- a beta particle (symbol β)
- a gamma ray (symbol γ)

Many radioactive substances emit α particles and β particles as well as γ rays[2].

1.1 Gamma Rays:

Gamma rays are waves, not particles. This means that they have no mass and no charge. Gamma rays have a high penetrating power - it takes a thick sheet of metal such as lead, or concrete to reduce them significantly. Gamma rays do not directly ionize other atoms, although they may cause atoms to emit other particles which will then cause ionization.

Gamma rays (γ) are electromagnetic waves, rather like X rays and radio waves. Thus gamma rays have no mass and no charge.

After a nucleus has emitted an α-particle or a β-particle, it may still have too much energy: we say it is in an "excited state". It can get rid of this energy by emitting a pulse of very high frequency electromagnetic radiation, called a gamma ray. Gamma rays do not pull electrons off atoms they pass, as α-particles and β-particles do. This means that they do not lose much energy as they travel, as they do not interact as much with the matter they pass. Therefore, gamma rays have a high penetrating power, and a very long range.

It's worth noting that there is no such thing as a pure γ-ray source. Gamma rays are given off by most α-emitters and β-emitters. If we want a source of pure gamma rays, we can get it by using a substance that emits both β and γ, and simply keep it in an aluminum container that stops the β-particles.

Useful gamma sources include Technetium-99m, which is used as a "tracer" in medicine. This is a combined β and γ source, and is chosen because betas are less harmful to the patient than alphas (less ionization) and because Technetium has a short half-life (just over 6 hours), so it decays away quickly and reduces the dose to the patient. In Gamma decay, both atomic number and atomic mass remain unchanged.[2]

1.2 Alpha Particles:

Alpha particles are made of 2 protons and 2 neutrons. This means that they have a charge of +2, and a mass of 4 *(the mass is measured in "atomic mass units", where each proton & neutron=1).* Alpha particles are relatively slow and heavy. They have a low penetrating power - you can stop them with just a sheet of paper. Because they have a large charge, alpha particles ionize other atoms strongly and have a range of only a few centimeters in air.

Alpha particles are made of 2 protons with 2 neutrons. This means that when a nucleus emits an alpha particle, it loses 2 protons and so its atomic number decreases by 2. Also, when a nucleus emits an alpha particle, its atomic mass decreases by 4 (that's 2 protons plus 2 neutrons). So Americium-241 (an α - source used in smoke detectors), which has an atomic number of 95 and an atomic mass of 241 will decay to Neptunium-237 (which has an atomic number of 93 and an atomic mass of 237). [3][4]

The equation would look like this:-

$$^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}\alpha$$

Alpha-decay occurs in

very heavy elements, for example, Uranium and Radium. These heavy elements have too many protons to be stable. They can become more stable by emitting an alpha particle.[2]

1.3 Beta Particles:

Beta particles have a charge of minus 1, and a mass of about 1/2000th of a proton. This means that beta particles are the same as an electron. They are fast, and light. Beta particles have a medium penetrating power - they are stopped by a sheet of aluminum or plastics such as Perspex. Beta particles ionize atoms that they pass, but not as strongly as Alpha particles do.

It appears strange that when the nucleus contains protons and neutrons,

we need to know more about protons and neutrons:

Protons & neutrons are made of combinations of even smaller particles, called "quarks". Under certain conditions, a neutron can decay, to produce a proton plus an electron. The proton stays in the nucleus, whilst the electron flies off at high speed.

This means that when a nucleus emits β-particle

-the atomic mass is uncharged .

-the atomic number increased by 1.

This is because a neutron has charged into proton.

$$^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + \beta$$

Beta decay occurs in very "neutron-rich" elements, for example, Strontium-90 and Iodine-130. These elements are typically created in nuclear reactors.

These elements have too few protons and too many neutrons to be stable. They can thus become more stable by emitting a beta particle.

Beta particles have a charge of -1, and weigh only a tiny fraction of a neutron or proton. As a result, β particles interact less readily with other

Other atoms than alpha particles.

Thus beta particles cause less ionization than alphas, and have a longer range, typically a few meters in air. In Beta decay, the atomic number increases by one while the atomic mass remains unchanged.[4][3]

2.0 Detection of Radioactivity:

Although some forms of electromagnetic energy, such as light and heat, can be detected by the human senses. One of the greatest draw backs to high energy radiation is the inability to detect it. We cannot see, feel, taste, smell, or hear the various forms of ionizing radiation. Fortunately, ionizing radiation interacts with matter which makes detection and measurement possible by utilizing specialized equipment. In this section we want to introduce you to the various ways and means of detecting and measuring ionizing radiation.

Becquerel discovered radioactivity because it left marks on photographic film. However, there are more definitive means commonly used by scientists and technicians who study and work with radiation. The equipment utilized for the detection and measurement of radiation commonly employs some type of substance or material that responds to radiation. Many common methods use either an ionization process or molecular excitation process as a basis. Remember that radiation interacts with matter. For detection and measurement purposes the process of ionization is the most commonly employed technique, based on the principle of charged particles producing ion pairs by direct interaction. These charged particles may collide with electrons, which remove them from their parent atoms, or transfer energy to an electron by interaction of electric fields[.3] [5]

3.0 Measurement of Radioactivity:

For measuring radioactivity, three types of devices are available:

1.Gas-filled tube counters e.g. the Geiger Muller Counter

2. Scintillation Counters

3.Semi-conductor Detectors

3.1 The Geiger Counter: A potential difference just below that required to produce a discharge is applied to the tube (1000 V). Any atoms of the gas struck by the γ-rays entering the tube are ionized, causing a discharge. Discharges are monitored and counted by electronic circuitry and the output is reported as counts/sec or Roentgens/hr or mR/hr.[2] One of the first and most sensitive devices employed to detect and measure low levels of ionizing radiation. He underlying principle is based on the emission of radiations that remove electrons from the atoms it strikes producing ions which passes through the oppositely charged plates resulting in a flow of current which is read on a meter. Geiger counter apparatus consists of Argon and Neon gas filled metal tube. A thin wire acts as a metal conductor with applied voltage of 500 volts, runs inside the tube to a connector on the tube body.[8]

3.2 Scintillation Counters: Crystals of certain substances e.g. cesium fluoride, cadmium tungstate, anthracite and sodium iodide emit small flashes of light when bombarded by γ-rays. The most commonly used phosphor in scintillation counters is NaI with a minute quantity of thallium added. In the instrument, the crystal is positioned against a photocell which in turn is linked to a recording unit. The number of flashes produced per unit time is proportional to the intensity of radiation. Small portable scintillation counters are available.[2]. Uses of scintillation detectors: It is an important component of imaging and non-imaging devices such as scintillation well counters and thyroid probes[9].
[10].

3.3 Semi-Conductor Detectors: A semi-conductor is a substance whose electrical conductivity is between that of a metal and an insulator. It is noted that Ge(Li) semi-conductors ate excellent detectors of γ-rays with a resolution ten times higher than NaI (Th) scintilla meters. The main disadvantage of these is a lower efficiency for higher energy x-rays. Besides, Ge(Li) semi-conductors need to be cooled by liquid nitrogen and are hence cumbersome and not suitable as field instruments.
Besides the above there are instruments known as γ-ray spectrometers, which can distinguish different energy peaks and hence make it possible to identify the source of radiation.[3]

A Geiger counter will record "counts per minute", but this doesn't tell us what the radioactive substance is actually doing, merely what is reaching the detector. It also tells us nothing about the amount of damage being done to you. [2]

3.4 Alpha and/or beta counting Another quantitative technique for accurate quantification of contamination in a sample. Alpha and/or beta counting apparatus consists of a thin ZnS layer coupled to a photomultiplier tube which is positioned in a shielded vacuum chamber to remove background radiation and radiation absorption by air.[11]

4.0 Safety Precautions:

Some of the principle safety precautions commonly used in working with radioactivity/radiation are time, distance, and shielding. Recall our earlier discussion of the dentist wanting to photograph your teeth. Have you ever wondered why the dentist lays a heavy apron across your chest? The dentist is practicing a means of protection from exposure. In that, they are using distance and shielding from the source of radiation. The concepts of these three principles are fairly simple. The first principle is time. The less time you spend around a radioactive material the less exposure you will receive. The second principle states that the greater the distance away from a radioactive source the lesser your exposure to the radiation. Lastly, if you can protect yourself with some type of material to act as a shielding device you will also reduce your overall exposure.

5.0 Objective:

There are six main objectives for this work as noted below:

1- To detect and measure gamma, beta and alpha rays from their sources by using Multichannel Analyzer.

2-To be familiar with Multichannel Analyzer, and study it's principle of action.

3-To find if there is a relationship between changes of energy levels, fine gain or source mass and amount of gamma , beta or alpha rays, respectively.

4-To study the functions and operations of the components of a gamma-

ray spectrometer.

5-To use a beta detector system.

6-To use an alpha detector system.

6.0 Materials:

1-Multichannel Analyzer.

2-Gamma rays sources (cesiom-137 and cobalt-60).

3-Gamma detector.

4-Beta rays sources (Thorium\Monazite and Sr-90).

5-Beta detector.

6-Alpha rays sources (Am-241, and Monazite ore).

7-Alpha detector.

7.0 Apparatus:

7.1Part A – Gamma rays

NaI(Tl) Gamma ray detector , Pan ax Equipment Limited Red hill Surrey.

1. Timer and counter, ORTEC 871.(**figure 1** shows it)

2. Single Channel Analyser, SCA 2031 Canberra
3. Amplifier 1416B Canberra
4. HV Power Supply, Model 3102 Canberra
5. Oscilloscope, Kenwood CS-4025 20MHz
6. ^{137}Cs and ^{60}Co sources

7.2Part B – Beta particles

1. Beta detector (scintillation detector).
2. Timer and counter, ORTEC 871.**(figure 2** shows it.)
3. Main Amplifier, Model CAV-N-1 ELSCINT
4. HV Power Supply, Model 3102 Canberra
5. Oscilloscope, Kenwood CS-4025 20MHz
6. Monazite ore.

7.3Part C – Alpha particles

1. Scintillation Alpha Counter, Model SAC-4 EBERLINE (**figure 3** shows it)
2. Weight machine, Stanton F4P (160g max)
3. Monazite ore.

Figure 1: Gamma counter

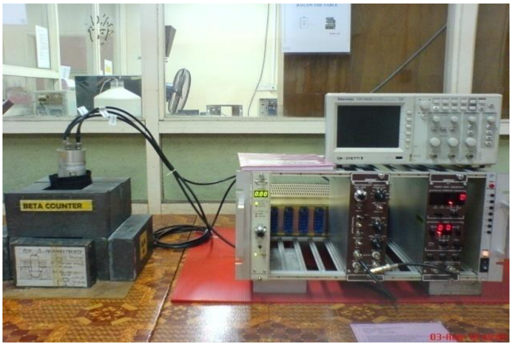

Figure 2: Beta counter

Figure 3: Alpha counter

8.0 Procedure:

8.1Part A – Gamma rays

a. Study the connection of various components of the radiation detection system.

b. Place the ^{137}Cs source inside the lead castle.

c. Set the component of the system as follows:

i. High voltage : 1000V

ii. Amplifier: Coarse Gain 64, Fine Gain 1

iii. SCA : Window, $\Delta E = 0.5$

iv. Counter: Preset 0.01, continue time = 20s

d. Obtain the count for value of E=0 to E=10 with steps 0.5.

e. Measure the count rate of the background.

f. Plot a graph of count rate versus E.

g. Repeat with different amplifier setting, using the Fine Gain setting of 2,3 and 5.

h. Basing on the data obtained, choose a suitable setting of the amplifier.

i. Obtain the count rate for ^{60}Co for different values of E.

j. By using the chosen setting in procedure (h), procedure (d) to (f) are repeated by using the ^{60}Co source and counting time 50s and 200s.

5.2 Part B – Beta particles

a. Study the connection of various components of beta particles radiation detection system

b. Set the component as follows:

i. High voltage : 1000V.

ii. Amplifier : Coarse Gain 50.

iii. Counter : Continue time = 20s.

c. Obtain background count rate with fine gain 1, 3, 5, 7, 9.

d. Place the Monazite ore blanched inside the sample chamber and obtain the count rate using Fine Gain 1,3,5, 7 and 9.

e. Repeat procedure (b) to (d) using Coarse Gain 100.

8.2 Part C – Alpha particles

a. On the power supply for scintillation alpha counter and obtain the background count rate with 2 minutes counting time.

b. Obtain the count rate for ^{241}Am source with the same Counting time .

c. Calculate the efficiency of the detector.

d. Obtain the count rate for various weights of Monazite ore (from 0.1g to 1.0 g).

9.0 Results And Discussion:

9.1 Part A – Gamma rays

The component of gamma ray detection system used in this work as shown below,

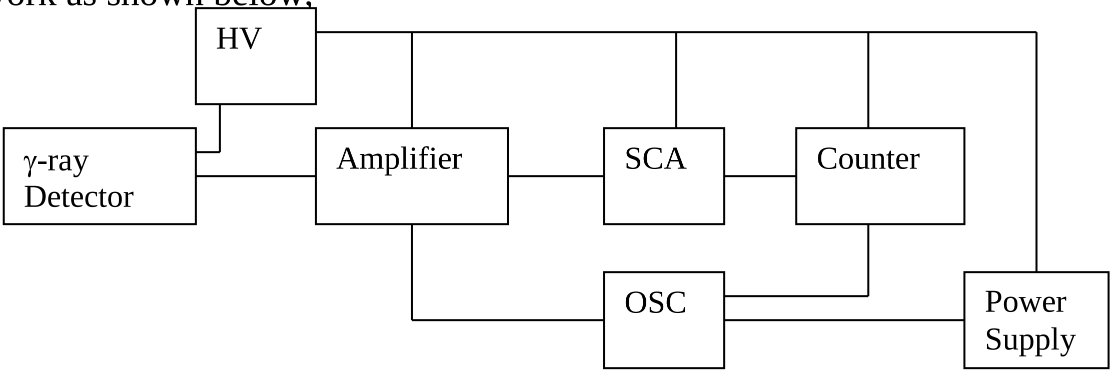

Figure 4: Component of gamma ray detection system

The data collected from Part A(see to Appendix1) is summarized and presented in the form of plotted graphs as shown below,

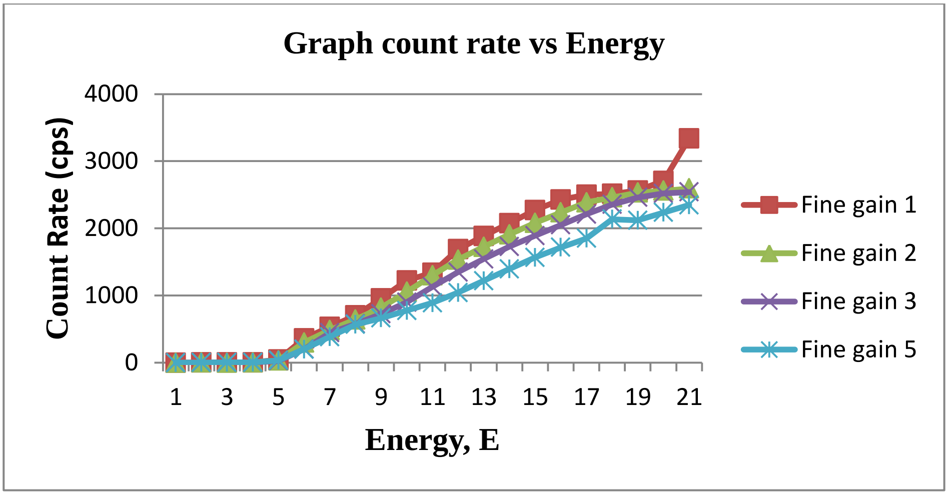

Figure 5: The plotted graph of counts/s versus E (energy channel) for various fine gain.

Due to the graph, we see that the fine gain 2 is more stable than the others so we use the fine gain 2 for gamma co-60. As we see in fine gain 1,2,3, and 5 for diagram of Cs-137 we can notice that the graphs of gamma ray for each gain almost is similar to each other , we notice that clearly with figure 5 with fine gain=2which we can see in it is more stable gain of gamma ray .

So the Figure 5 :shows that the graph plotted each fine gains as straight line in beginning of count rate at the beginning fine gain. This is because of the stability of counter instrument due to rich BNC cable contact. During this work any movement and touch of the cable are found will interfere the count reading. Fine gain 2 is more reliable compare to the other fine gains because it can gives the clear photo of Cs-137 energy spectra at the higher energy side..So fine gain2 is a choice for Co-60 energy spectra.

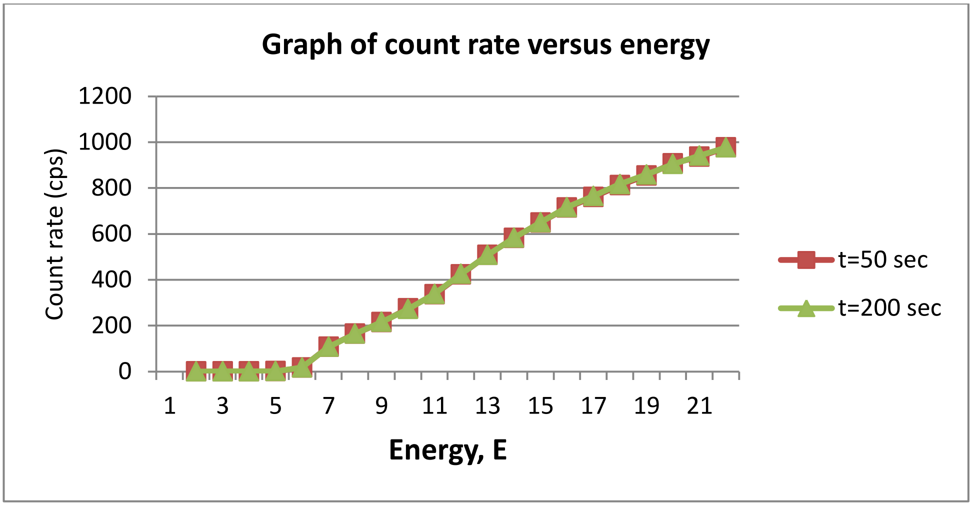

Figure 6: The plotted graph of counts/s versus E (energy channel) for a radioactive source Co-60 measured at two different times.

From the figure 6 we see the graph of co-60 at time=50s,t=200s is identical. The counts for Co-60 source are taken for two different times (50 s and 200 s). The result is shown in Figure 6 where the count rate for each measurement is about the same. This is also consistent with the result of previous measurement for Co-60 in term of graph pattern in Figure 6.

9.2 Part B: Beta Particles

The component of Beta particle detection system used in this work is shown below as in Diagram 1,

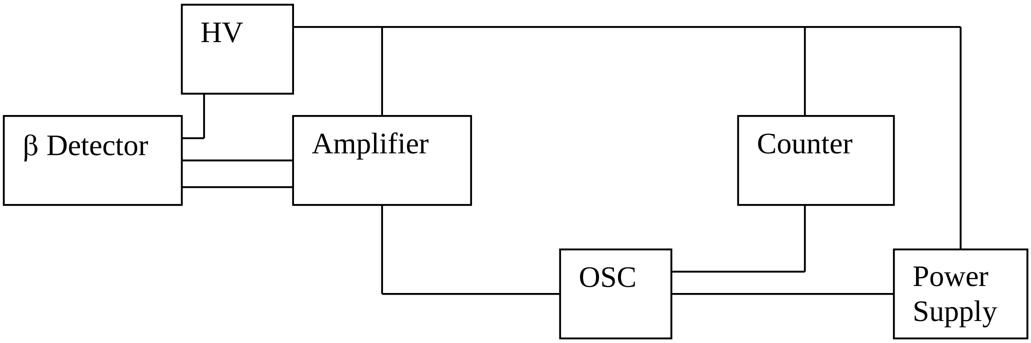

Figure 7.1: Component of Beta particle detection system

The data collected for part B(see to Appendix2) is summarized and presented in the form of plotted graphs as shown below,

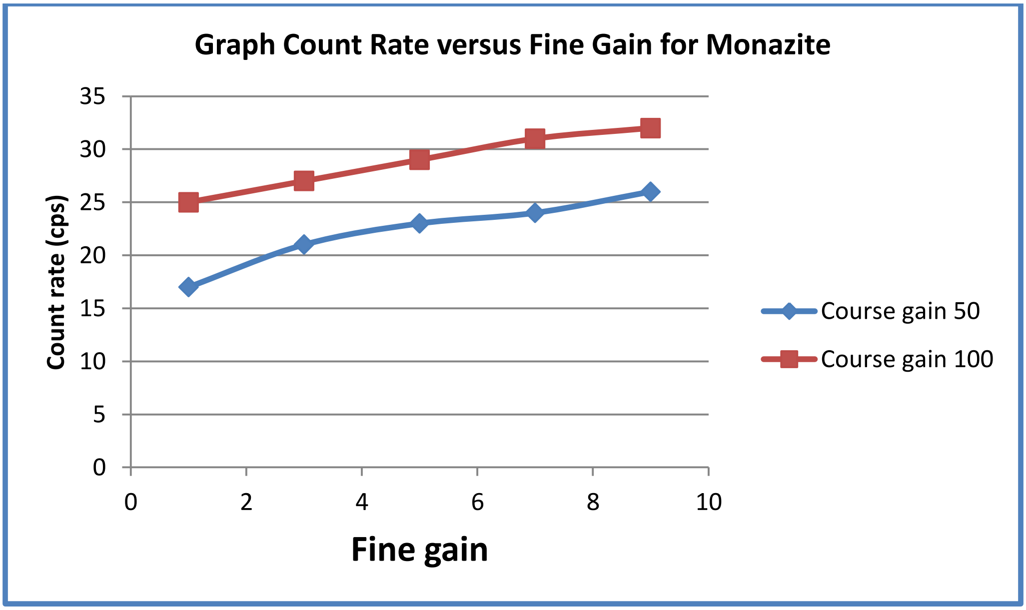

Figure 8: Plotted graph of counts versus fine gain for two different course gains

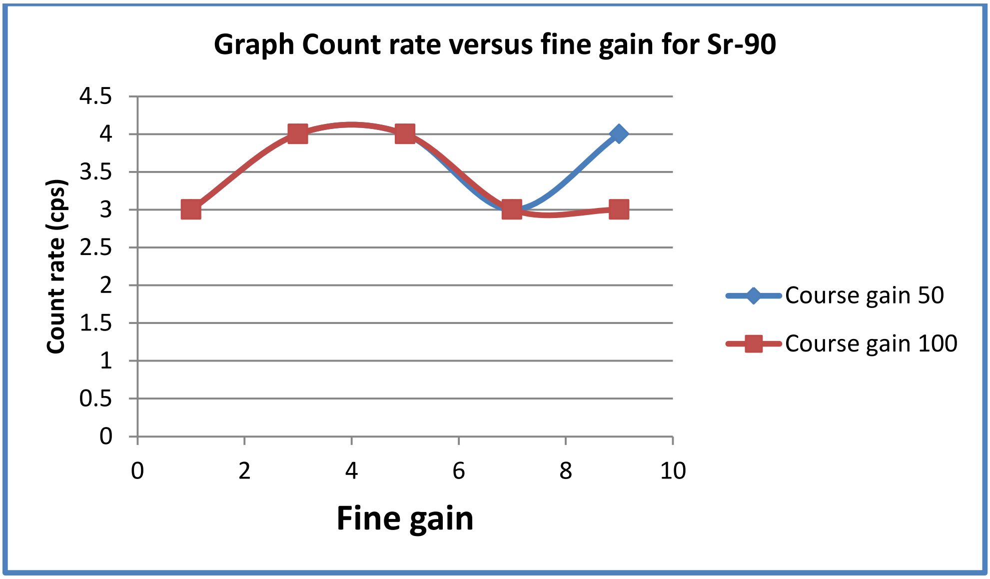

Figure9: the graph plot for counts obtained using course gain 100/50

From the figure 8: The gain is normally adjustable over the wide range through a combination of coarse gain and fine gain controls. If the product of input amplitude and gain exceeds the maximum design output amplitude, the amplifier will saturate or limit and produce a distorted output pulse with a flat top at the amplitude at saturation occurs. Figure 8 shows that the coarse gain 100 count rate is higher than course gain 50 for each set of fine gain 1, 3, 5, 7 and 9 respectively.

From the figure 9: we find The gain is normally not systematic range through a combination of coarse gain and fine gain controls. If the product of input amplitude and gain exceeds the maximum design output amplitude, the amplifier will saturate or limit and produce a distorted output pulse with a flat top at the amplitude at saturation occurs.

From figure 8,9: Also the count rate is increased as the course gain of amplifier is increased. Soothe count rate of the radioactive source has been detected is proportion to the coarse gain , where the coarse gain is the applied voltage to the detection of beta emission of the detector has been used. From the figure the count rate is nearly remains constant with the increasing of fine gain .from the figure the count rates sr-90 source were obtained are unpredicted. So the count rate should be nearly constant as the figure .this occurrence of experimental error might be due to temperature variation or rate dependence of the detector .if the rate is too high ,as second signal might occur before the first signal has ended.

9.3 Part C: Alpha Particles

Background count rate for scintillation alpha counter is shown in Table 3.1, this is taken before measuring the count rate for alpha particles emitted by ^{241}Am and the net counts rate is calculated as in Table3.2 :

Background : Time= 2minutes

Table 3.1: Background counting for Scintillation Alpha Counter

Count Reading					
1	2	3	4	5	Average
84	91	87	109	90	92

Table 3.2: Counting for a radioactive sources Am-241 MONAZITE ORE:

Count Reading						Net count	Count rate (cps)
1	2	3	4	5	Average		
1306	1357	1312	1370	1415	1352	1260	11

AM-241: Time= 2minutes

Table 3.3: Counting for a radioactive sources monazite ore

Weight (g)	Reading						Net count	Count rate (cps)
	1	2	3	4	5	Average		
0.1163	351	364	361	353	359	358	266	2.216666667
0.2229	418	399	453	406	416	418	326	2.716666667
0.3108	515	505	512	494	470	499	407	3.391666667
0.423	556	588	551	530	526	550	458	3.816666667
0.5009	652	635	650	631	639	641	549	4.575
0.735	723	668	737	686	689	701	609	5.075
0.8017	729	703	720	737	728	723	631	5.258333333
1.0455	832	779	787	796	770	793	701	5.841666667

Figure 10: Graph for count vs monazite weight

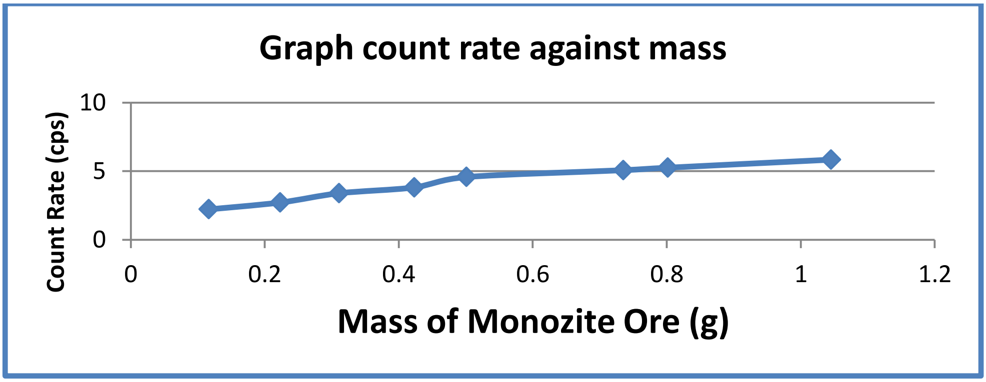

Figure 10 shows that the graph plotted is almost linear, the counts/s is proportionally increasing with weight (g) of Monazite ore. Monazite is an important ore for thorium, lanthanum and cerium but in this measurement is specified to thorium that decays into lead and producing alpha particle. The counts/s is increasing due to the increase of the activity of thorium radioactive nuclei in Monazite ore. This activity (A) is proportional to the number of nuclei, N, as shown in this equation; $A = \lambda N$, where as λ is known as decay constant (s^{-1}).

When using a particle counting instrument, one must remember to measure a background first. The net number of counts is then obtained by subtracting the background from the actual number of counts produced by the source. Due to statistical processes for both nuclear disintegration and measurement itself, subtraction of background is trivial only when the counting rates are much greater than background. When they are close to each other, a statistical decision must be taken using the "detection limit" formula (DL):

$$DL = \frac{3 + (4.65 \sqrt{bg})}{CT}$$

Where "bg" means number of counts of background, CT means counting time in second, and DL is in unit counts per second (cps). For this case of experiment detecting radiation from Am-241 above, detection limit of detector used is;

$$DL = \frac{3 + (4.65\sqrt{92})}{120s} = 9.5 \text{ cps}$$

And it shows that the difference between sample measurement (11 cps) and background (0.7cps) is bigger than the detection limit (9.5 cps), the measurement is considered statistically significant and the result is expressed as:

$$DE = \frac{\text{Nett Count (cps)}}{\text{Activity (dps)}}$$

Where DE is the efficiency of the detection process, and can be performed in percentage by multiplying with100 %. For direct measurement, or measurement of a liquid sample, DE simply represents detector efficiency. This efficiency is determined by measuring samples of known activity (calibrated sources) under similar conditions. That is why it's very important to have the detection system properly calibrated.

10.0 Determination of efficiency of alpha counter:-

From Knowing the ^{241}Am half life, $t_{1/2}$ and the initial activity, A_o, the activity of this radio nuclei can be calculated as below;

^{241}Am Half Life, $t_{1/2}$ = 433 y

Activity on 19/01/1982, A_o = 216.6 Bq

$A = A_o e^{-\lambda t}$

$\lambda = \ln 2 / t_{1/2} = 0.6931/ 433\ y = 1.6 \times 10^{-3}\ y^{-1}$

Time from 19/01/1982 to 27/07/2017, t =35.52 y

$A = A_o e^{-\lambda t}$ = 216.6 Bq e^ ($-1.6 \times 10^{-3}\ y^{-1} \times 35.52y$) = 204.6 Bq

Activity on 27/07/2017, A = 204. 6Bq =204. 6 dps.

The efficiency of alpha detector can be measured by obtaining the ratio of count per second (cps) to decay per second (dps) as shown by equation below;

Net count of Am-241=1352-92=1260

Net count rate of Am-241=1260count/120second=10.5

Efficiency of detector, DE = (cps/dps) x 100

DE = (10.5/204.6) x 100 = 5.14 %

This efficiency is actually very low because of 94.86% of nuclei disintegration can't be detected by the detector.

11.0 Conclusion:

Radiation detection involves the detection and investigation of ionizing radiations. The passage of an ionizing radiation through the detector results in energy dissipation through a burst of ionization. This burst of ionization is converted into an electrical pulse that actuates a readout device, to register a count. There are several factors affecting the measurement result of ionizing radiation detection of gamma rays, beta and alpha particle in this work, the utmost important is the condition of detection system itself. The ability of the detector to count as much as possible the ionizing radiation compare to the number of disintegration of radio nuclei is called detection efficiency. The efficiency of the detector is related to the performance of each component in the integrated detection system such as the detector itself, HV component, amplifier and pre-amplifier, timer and the counter. These components are connected with cable, and this connection is crucial to be in a good condition to make sure that the detection system will be fully functioned. The maintenance and calibration, and the proper handling of the detection system are necessary in order to get a good result of radiation detection and measurement.

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Appendix 1:

Data for Part A: Gamma Rays

Fine gain 1

Background counting (20 sec)

Energy	Reading			
	1	2	3	Average
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	0	0
1.5	0	0	0	0
2.0	2	1	2	2
2.5	39	38	41	39
3.0	94	104	100	99
3.5	138	137	158	144
4.0	162	158	159	160
4.5	190	165	163	173
5.0	176	200	192	189
5.5	233	184	191	203
6.0	212	226	227	222
6.5	246	270	265	260
7.0	272	253	258	261
7.5	263	318	259	280
8.0	302	325	290	306
8.5	310	318	309	312
9.0	351	340	333	341
9.5	354	332	292	326
10.0	323	371	346	347

Cesium-137 (20 sec)

Energy	Reading				Net count	Count rate (cps)
	1	2	3	Average		
0.0	0	1	3	1	1	0
0.5	31	37	31	33	33	2
1.0	65	73	65	68	68	3
1.5	112	111	99	107	107	5
2.0	862	919	943	908	906	45

2.5	7195	7192	7179	7189	7150	358
3.0	10800	10760	10644	10735	10636	532
3.5	14095	14270	14271	14212	14068	703
4.0	19222	19206	19305	19244	19084	954
4.5	24635	24401	24873	24636	24463	1223
5.0	29291	29616	20739	26549	26360	1318
5.5	34062	33959	33955	33992	33789	1689
6.0	38025	37881	37985	37964	37742	1887
6.5	41486	41870	42017	41791	41531	2077
7.0	45749	45829	45443	45673.67	45412.7	2271
7.5	48723	49052	48644	48806.33	48526.3	2426
8.0	50463	50375	50057	50298.33	49992.3	2500
8.5	50598	50493	50636	50575.67	50263.7	2513
9.0	51540	51556	51657	51584	51243	2562
9.5	54587	54560	54112	54420	54094	2705
10.0	66974	67347	67051	67124	66777	3339

Fine gain 2

Background counting (20 sec)

Energy	Reading			
	1	2	3	Average
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	0	0
1.5	0	0	0	0
2.0	2	10	3	5
2.5	36	43	43	41
3.0	100	83	100	94
3.5	142	130	134	135
4.0	153	144	156	151
4.5	175	185	183	181
5.0	210	198	192	200
5.5	221	204	235	220
6.0	236	221	220	226
6.5	236	244	247	242
7.0	242	279	264	262
7.5	304	280	277	287

8.0	301	275	295	290
8.5	276	295	324	298
9.0	312	348	330	330
9.5	329	366	351	349
10.0	383	333	338	351

Cesium-137 (20 sec)

Energy	Reading				Net count	Count rate (cps)
	1	2	3	Average		
0.0	2	0	1	1	1	0
0.5	32	36	32	33	33	2
1.0	54	56	69	60	60	3
1.5	107	96	108	104	104	5
2.0	615	646	653	638	633	32
2.5	5948	6097	6075	6040	5999	300
3.0	9735	9749	9920	9801	9707	485
3.5	12998	13047	12958	13001	12866	643
4.0	16669	16444	16456	16523	16372	819
4.5	21187	21442	21226	21285	21104	1055
5.0	26268	26163	26234	26222	26022	1301
5.5	30834	30749	31055	30879	30659	1533
6.0	34698	34487	34969	34718	34492	1725
6.5	38054	38601	38598	38418	38176	1909
7.0	41476	41964	42201	41880	41618	2081
7.5	45051	44758	45181	44997	44710	2236
8.0	48125	47753	48197	48025	47735	2387
8.5	49845	49984	48687	49505	49207	2460
9.0	50653	51229	50995	50959	50629	2531
9.5	51662	51574	51409	51548	51199	2560
10.0	52734	51678	52257	52223	51872	2594

Fine gain 3

Background counting (20 sec)

Energy	Reading			
	1	2	3	Average
0.0	0	0	0	0
0.5	0	0	0	0

1.0	0	0	0	0
1.5	0	0	0	0
2.0	3	7	9	6
2.5	45	29	38	37
3.0	109	96	69	91
3.5	122	129	132	128
4.0	173	141	144	153
4.5	176	159	193	176
5.0	203	211	201	205
5.5	205	211	220	212
6.0	226	237	238	234
6.5	263	272	251	262
7.0	283	292	256	277
7.5	264	269	275	269
8.0	298	278	281	286
8.5	272	315	302	296
9.0	327	307	295	310
9.5	334	348	327	336
10.0	339	369	350	353

Cesium-137 (20 sec)

Energy	Reading				Net count	Count rate (cps)
	1	2	3	Average		
0.0	2	0	0	1	1	0
0.5	32	36	32	33	33	2
1.0	58	68	64	63	63	3
1.5	81	100	80	87	87	4
2.0	507	473	525	502	496	25
2.5	4038	4058	4157	4084	4047	202
3.0	8961	9020	9005	8995	8904	445
3.5	11769	11766	11599	11711	11583	579
4.0	14621	14649	14694	14655	14502	725
4.5	18048	18203	18205	18152	17976	899
5.0	22694	22976	22702	22791	22586	1129
5.5	27079	27109	27285	27158	26946	1347
6.0	30921	31146	31136	31068	30834	1542

6.5	34638	34916	34937	34830	34568	1728
7.0	37884	38343	38072	38100	37823	1891
7.5	41054	41559	41252	41288	41019	2051
8.0	44550	44431	44411	44464	44178	2209
8.5	47615	47635	46992	47414	47118	2356
9.0	49500	49343	49727	49523	49213	2461
9.5	50882	50522	50796	50733	50397	2520
10.0	51065	51039	51424	51176	50823	2541

Fine gain 5

Background counting (20 sec)

Energy	Reading			
	1	2	3	Average
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	0	0
1.5	0	0	0	0
2.0	3	1	0	1
2.5	45	47	59	50
3.0	65	70	71	69
3.5	95	92	141	109
4.0	180	187	189	185
4.5	189	205	197	197
5.0	210	204	213	209
5.5	262	223	260	248
6.0	263	250	263	259
6.5	288	271	282	280
7.0	288	284	277	283
7.5	289	299	310	299
8.0	337	294	286	306
8.5	302	299	306	302
9.0	326	329	320	325
9.5	324	314	316	318
10.0	341	355	333	343

Cesium-137 (20 sec)

Energy	Reading				Net count	Count rate (cps)
	1	2	3	Average		
0.0	2	0	2	1	1	0
0.5	36	30	23	30	30	2
1.0	56	63	68	62	62	3
1.5	98	79	77	85	85	4
2.0	724	616	767	702	701	35
2.5	4026	4063	4052	4047	3997	200
3.0	7865	7675	7771	7770	7701	385
3.5	11413	11458	11520	11464	11355	568
4.0	13302	13409	13645	13452	13267	663
4.5	15803	15720	15564	15696	15499	775
5.0	18062	17856	18030	17983	17774	889
5.5	20945	21240	21063	21083	20835	1042
6.0	24684	24691	24482	24619	24360	1218
6.5	28393	28005	28292	28230	27950	1396
7.0	31562	31587	31731	31627	31344	1567
7.5	34532	34705	34599	34612	34313	1716
8.0	37183	37410	37401	37331	37025	1851
8.5	49178	39995	39907	43027	42725	2136
9.0	42761	42559	42775	42698	42373	2119
9.5	45239	44886	45059	45061	44743	2237
10.0	47272	47328	47311	47304	46961	2348

Cobalt-60

Fine gain 2

Background counting (50 sec)

Energy	Reading			
	1	2	3	Average
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	0	0
1.5	0	0	0	0
2.0	23	24	19	22
2.5	143	102	132	126
3.0	382	292	279	318
3.5	408	392	428	409
4.0	533	512	527	524

4.5	632	674	629	645
5.0	654	665	622	647
5.5	632	674	727	678
6.0	739	742	720	734
6.5	795	790	788	791
7.0	859	823	834	839
7.5	874	884	839	866
8.0	937	906	927	923
8.5	944	909	998	950
9.0	999	981	979	986
9.5	1072	996	979	1016
10.0	962	975	956	964

Cobalt-60 (50 sec)

Energy	Reading				Net count	Count rate (cps)
	1	2	3	Average		
0.0	0	0	0	0	0	0
0.5	8	8	20	12	12	0
1.0	32	30	31	31	31	1
1.5	47	57	44	49	49	1
2.0	821	888	856	855	833	17
2.5	5574	5542	5449	5522	5396	108
3.0	8484	8625	8477	8529	8211	164
3.5	11149	11221	11026	11132	10723	214
4.0	13980	14308	14523	14270	13746	275
4.5	17223	17370	17742	17445	16800	336
5.0	21633	21946	21703	21761	21114	422
5.5	26103	26117	26042	26087	25410	508
6.0	29642	29883	29900	29808	29075	581
6.5	33448	33039	33244	33244	32453	649
7.0	36612	36282	36705	36533	35694	714
7.5	38720	38877	39129	38909	38043	761
8.0	41510	41921	41143	41525	40601	812
8.5	43820	43918	43246	43661	42711	854

9.0	46355	46520	46242	46372	45386	908
9.5	47637	47807	47997	47814	46798	936
10.0	49555	49940	49882	49792	48828	977

Background counting (200 sec)

Energy	Reading			
	1	2	3	Average
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	0	0
1.5	0	0	0	0
2.0	28	31	32	30
2.5	387	377	377	380
3.0	966	1055	1055	1025
3.5	1366	1482	1384	1411
4.0	1932	2085	1960	1992
4.5	2242	2149	2116	2169
5.0	2333	2291	2301	2308
5.5	2457	2361	2339	2386
6.0	2608	2621	2604	2611
6.5	2635	2670	2628	2644
7.0	2783	2795	2765	2781
7.5	2911	2934	3021	2955
8.0	3065	3157	3190	3137
8.5	3341	3368	3199	3303
9.0	3440	3403	3403	3415
9.5	3667	3588	3640	3632
10.0	3761	3639	3716	3705

Cobalt-60 (200 sec)

Energy	Reading				Net count	Count rate (cps)
	1	2	3	Average		
0.0	2	1	2	2	2	0
0.5	51	57	64	57	57	0
1.0	124	118	121	121	121	1
1.5	203	193	190	195	195	1
2.0	3490	3506	3592	3529	3499	17
2.5	22116	21778	21768	21887	21507	108
3.0	34096	34017	33712	33942	32916	165

3.5	44810	44643	44227	44560	43149	216
4.0	56114	56404	56733	56417	54425	272
4.5	69199	69839	70473	69837	67668	338
5.0	87281	87534	87203	87339	85031	425
5.5	103655	103924	104284	103954	101569	508
6.0	119390	119255	119164	119270	116659	583
6.5	132884	132515	132703	132701	130056	650
7.0	146159	145860	146048	146022	143241	716
7.5	155201	156160	156508	155956	153001	765
8.0	166385	166881	166079	166448	163311	817
8.5	174875	175580	174695	175050	171747	859
9.0	184778	184492	183288	184186	180771	904
9.5	192169	192109	191308	191862	188230	941
10.0	199221	199107	198501	198943	195238	976

Appendix2

Data for Part B: Beta Particles

Coarse Gain 50

Background Counts

Fine gain	Reading					
	1	2	3	4	5	Average
1	128	143	141	124	125	132
3	151	146	161	146	157	152
5	157	153	163	196	178	169
7	188	173	215	159	191	185
9	205	211	223	203	219	212

Monazite Counts

Fine gain	Reading						Net count	Count Rate (cps)
	1	2	3	4	5	Average		
1	1141	1132	1127	1181	1172	1151	1019	17

3	1436	1413	1416	1393	1431	1418	1266	21
5	1544	1629	1489	1573	1564	1560	1391	23
7	1615	1697	1694	1591	1636	1637	1452	24
9	1780	1770	1734	1739	1701	1745	1533	26

Strontium Counts

Fine gain	Reading						Net count	Count Rate (cps)
	1	2	3	4	5	Average		
1	406	394	419	360	428	401	175	3
3	474	444	485	427	464	459	218	4
5	520	462	489	481	508	492	221	4
7	470	484	478	507	467	481	195	3
9	512	552	531	500	559	531	228	4

Coarse Gain 100

Background Counts

Fine gain	Reading					
	1	2	3	4	5	Average
1	194	183	170	184	183	183
3	194	227	207	210	206	209
5	228	226	224	218	222	224
7	251	248	256	256	233	249
9	233	258	255	247	289	256

Monazite Counts

Fine gain	Reading						Net count	Count Rate (cps)
	1	2	3	4	5	Average		
1	1720	1782	1662	1631	1717	1702	1519	25
3	1788	1869	1893	1788	1905	1847	1638	27
5	1937	1990	1980	1963	1872	1968	1744	29
7	2089	2072	2115	2133	2104	2104	1855	31
9	2189	2182	2137	2176	2155	2168	1912	32

Strontium Counts

Fine gain	Reading						Net count	Count Rate (cps)
	1	2	3	4	5	Average		
1	480	460	488	512	495	487	208	3
3	560	557	546	529	535	545	236	4
5	595	592	561	614	610	594	226	4
7	721	687	677	656	669	682	187	3
9	815	745	827	874	833	819	168	3