NUCLEAR PHYSICS CALCULATOR J Component Project Report NUCLEAR AND PARTICLE PHYSICS PHY6002

Preprint · July 2021

6 authors, including:

Ayathuparambil MELBIN Richard
VIT University

Keerthana Krishna P
VIT University

Ajmal Ibn Mohammed Althaf
VIT University

Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

NUCLEAR PHYSICS CALCULATOR

J Component Project Report

Winter Semester 2019-20

Submitted as course project for

NUCLEAR AND PARTICLE PHYSICS

PHY6002

***Faculty*: Dr. C. Anuradha**

Submitted by

Delli Babu P (19MSP0003)

A Melbin Richard (19MSP0015)

Sri Aurobindo Panda (19MSP0027)

Keerthana Krishna P (19MSP0042)

Aswin J Tom (19MSP0059)

Ajmal Ibn Mohammed Althaf (19MSP0061)

CONTENTS:

1. Introduction
2. Theory
3. Coding and computation
4. Program Output
5. Result
6. Conclusion
7. Reference

Introduction

This project covers the J Component Project which was our course project for the second semester Nuclear and Particle Physics subject. Here, our work aims to design a nuclear physics calculator which includes some of the parameters used usually in nuclear physics areas and are helpful for many applications. This calculator includes Nuclear Radius, Impact Parameter, Radioactive Decay, Decay Constant, Nuclear Potential of shell model, Mass defect and Binding Energy as the parameters. The design is programmed using C++ language. C++ is a high level programming language which allows low level manipulation of data at a certain level. We have chosen C++ over other languages because of its high efficiency, generic and object-oriented characteristics. It is capable of running on small scale as well as large scale of data. We are interested in this particular topic in order to make the calculation in nuclear physics simple and easy. Just by providing the values to all the variables we will be able to get the calculated result for the parameters and this is the reason why we intended to take this as our project topic.

Theory

Nuclear radius

Since the time of Rutherford's scattering experiments, the nucleus, like the atom, is not a solid object with a well-defined surface. Furthermore, a multitude of other experiments have shown that most nuclei are approximately spherical some are notably ellipsoidal and have an average radius given by

$$r = r_0 A^{1/3}$$

Where r_0 is a constant equal to 1.2×10^{-15} m and A is the mass number. A convenient unit for measuring distances on the scale of nuclei is the femto meter (10^{-15} m).

Because the volume of a sphere is proportional to the cube of its radius, it follows from equation that the volume of a nucleus (assumed to be spherical) is directly proportional to A, the total number of nucleons. This proportionality suggests that all nuclei have nearly the same density.

When nucleons combine to form a nucleus, they combine as though they were tightly packed spheres. This fact has led to an analogy between the nucleus and a drop of liquid, in which the density of the drop is independent of its size.

Mass defect and Binding Energy

Mass defect can be defined as the difference in mass of the nucleus and total mass of the protons and neutrons inside the nucleus. It is also called as Mass deficit. Mass defect was discovered by Albert Einstein in 1905.

We can calculate mass defect by using this formula,

$$\boldsymbol{\Delta m = [Z m_p + (A - Z) m_n - M]}$$

where,

Δm = mass defect
Z = atomic number
A-Z= N = total no. of neutrons
m_n= mass of the neutron
m_p= mass of the proton
$m_n = m_p = 1.67 * 10^{-27}$ k.g
M= mass of the nucleus

This mass defect leads to the binding energy of the nucleus.

Binding energy is defined as the minimum energy require to separate the nucleons from the nucleus.It is always a positive number, as we need to spend energy in moving these nucleons, attracted to each other by the strong nuclear force, away from each other.It represents the energy that was released when the nucleus was formed.

There are several types of binding energy, each operating over a different distance and energy scale.The smaller the size of a bound system, the higher its associated binding energy. This energy may be made available as nuclear energy and can be used to produce electricity, as in nuclear power or in a nuclear weapon.

We can calculate binding energy by using this formula,

$$\Delta E_b = \Delta m * c^2$$
$$= [Zm_p + (A-Z)m_n - M] * c^2$$

which can also be written in eV as

$$\Delta E = \Delta m * 931 Mev$$
$$= [Zm_p + (A-Z)m_n - M] * 931 \text{ Mev}$$

The average value for binding energy per nucleon is 8Mev/nucleon.

Impact Parameter

The impact parameter is defined as the perpendicular distance between the path of a projectile and the centre of a potential field created by an object that the projectile is approaching. That is it is the perpendicular distance to the closest approach if the projectile were undeflected. The scattering angle depends upon the force and upon the impact parameter.

For the case of alpha scattering from nucleus of atomic number Z, the impact parameter can be formulated as,

$$b = \frac{Zke^2}{KE}\sqrt{\frac{1+\cos\theta}{1-\cos\theta}}$$

The expression for impact parameter can also be written as

$$b = \frac{Ze^2 \cot\frac{\theta}{2}}{4\pi\varepsilon_0(\frac{1}{2}mu^2)}$$

The expression for **distance of closest approach** for a nuclear size particle can also be written as

$$r_0 = \frac{2Ze^2}{4\pi\varepsilon_0(\frac{1}{2}mu^2)}$$

Nuclear Potential and Shell Model

In nuclear physics, the shell model is a model of the atomic nucleus which uses the pauli exclusion principle to describe the structure of the nucleus in terms of energy levels. The evidence for a kind of shell structure and a limited number of allowed energy states suggest that a nucleon moves in some kind of effective potential well created by the forces of all the other nucleons. This leads to energy quantization in a manner similar to the square well and harmonic oscillator potentials. Then the potential is with the correction terms of symmetrical and electrostatic repulsion energy are expressed as

$$\boldsymbol{V(r) = \frac{ZKe^2}{R_c}\left[1 + \frac{1}{2}\left(1 - \left(\frac{r}{R_c}\right)^2\right)\right] \; r < R_C}$$

$$\boldsymbol{V(r) = \frac{ZKe^2}{r} \; r > R_c}$$

where R_c is the charge radius, distinct from the model radius of the nuclear potential.

Radioactive Decay, Decay Constant and Half Life

In 1896, Becquerel accidentally discovered that uranyl potassium sulfate crystals emit an invisible radiation that can darken a photographic plate when the plate is covered to exclude light. After a series of experiments, he concluded that the radiation emitted by the crystals was of a new type, one that requires no external stimulation and was so penetrating that it could darken protected photographic plates and ionize gases. This process of spontaneous emission of radiation by uranium was soon to be called radioactivity.

There is absolutely no way to predict whether any given nucleus in a radioactive sample will be among the small number of nuclei that decay during any given second .All have the same chance. The decay process is probabilistic in nature and can be described with statistical calculations for a radioactive substance of macroscopic size containing a large number of radioactive nuclei. For such large numbers, the rate at which a particular decay process occurs in a sample is proportional to the number of radioactive nuclei present (that is, the number of nuclei that have not yet decayed).

If N is the number of undecayed radioactive nuclei present at some instant, the rate of change of N with time is

$$\frac{dN}{dt} = -\lambda N$$

Where , λ called the decay constant or disintegration constant , it is the probability of decay per nucleus per second. The negative sign in $\frac{dN}{dt}$ indicates that is negative; that is, N decreases in time.

The number of radioactive nuclei is given as a function of time by

$$N=N_0e^{-\lambda t}$$

where the constant N_0 represents the number of undecayed radioactive nuclei at $t = 0$. This is the law of radioactive decay. And shows that the number of undecayed radioactive nuclei in a sample decreases exponentially with time. N_0 is the number of radioactive nuclei in the sample at $t = 0$ and N is the number remaining at any subsequent time t.

There are two common time measures of how long any given type of radionuclides lasts. One measure is the half-life $T_{1/2}$ of a radionuclide , which is the time at which the quantity have been reduced to one-half their initial values. The other measure is the mean (or average) life τ, which is the time at which quantity have been reduced to e^{-1} of their initial values.

The half-life $T_{1/2}$ and the mean life are measures of how quickly radioactive nuclei decay occurs and are related by

$$T_{1/2} = \frac{\ln 2}{\lambda} = \tau \ln 2$$

Coding And Computation:

```
# include <iostream.h>
# include <math.h>
# include <conio.h>

int main()
{
clrscr();
    char o;
    float a1,a2,n,t,r,s;

    cout << "Enter nuclear paramaneter you have to calculate ";

    cout<<"\n 1.DECAY CONSTANT \n 2.RADIOACTIVE DECAY LAW(N) \n 3.BINDING ENERGY \n 4.SHELL MODEL(r>R) \n";
    cout<<" 5.SHELL MODEL(r<R) \n 6.TO FIND IMPACT PARAMETER \n 7.NUCLEAR SIZE \nENTERED OPTION : \t";

    cin >> o;



    switch(o)
    {
     case '1':
         cout <<"\n ENTER HALF LIFE";
         cin>>a1;
         a2=0.693/a1;
         cout<<"DECAY CONSTANT:"<<a2;
         break;
```

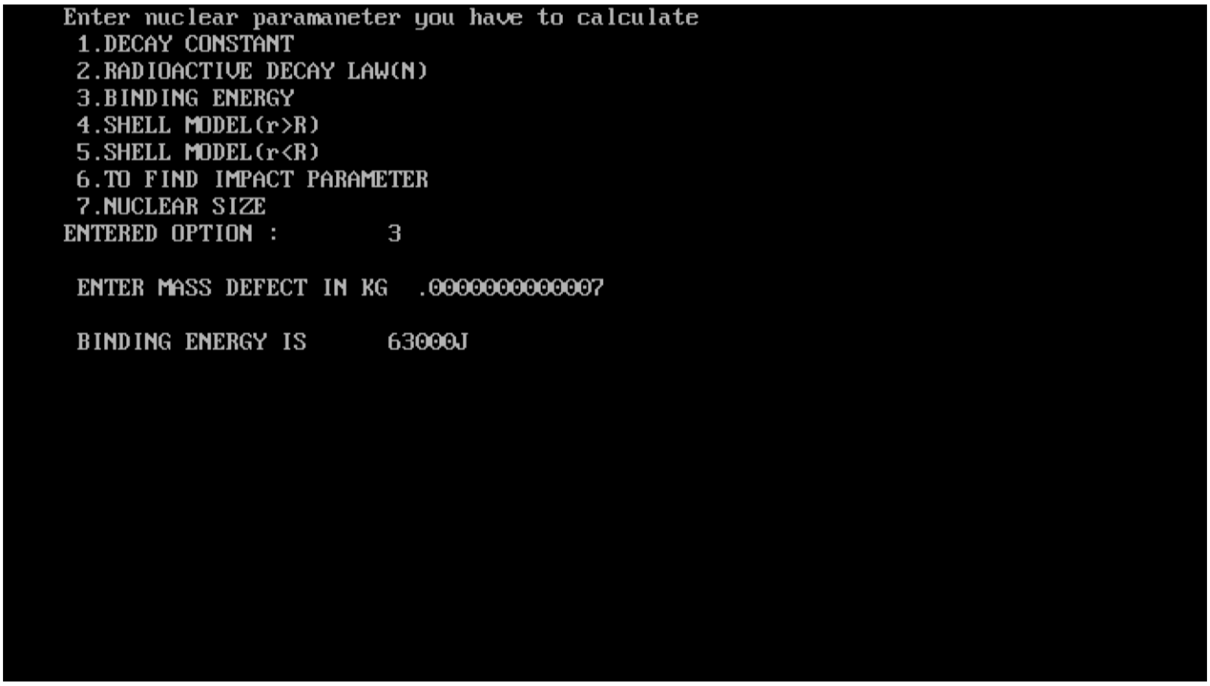
```
case '2':
  {  cout<<"ENTER N 0" ;
     cin>>a1;
     cout <<"ENTER DECAY CONSTANT:";
     cin>>a2;
     cout<<"ENTER TIME:";
     cin>>t;
    n=a1*exp(-a2*t);
    cout<<" \n DECAY LAW VALUE:"<<n;}
    break;
  case '3':
  {  cout<<" \n ENTER MASS DEFECT IN KG" ;
     cin>>a1;

    n=a1*300000000*300000000;
    cout<<"\n BINDING ENERGY IS \t"<<n<<"J";}
    break;
case '4':
  {cout<<"ENTER Z : " ;
     cin>>a1;
     cout <<"ENTER k:";
     cin>>a2;
     cout<<"ENTER r:";
     cin>>t;
     cout<<"ENTER R:";
     cin>>r;

    n=a1*a2*2.56/t;
    cout<<" \n THE NUCLEAR POTENTIAL IS"<<n<<"x 10^-38";}
    break;
case '5':
```

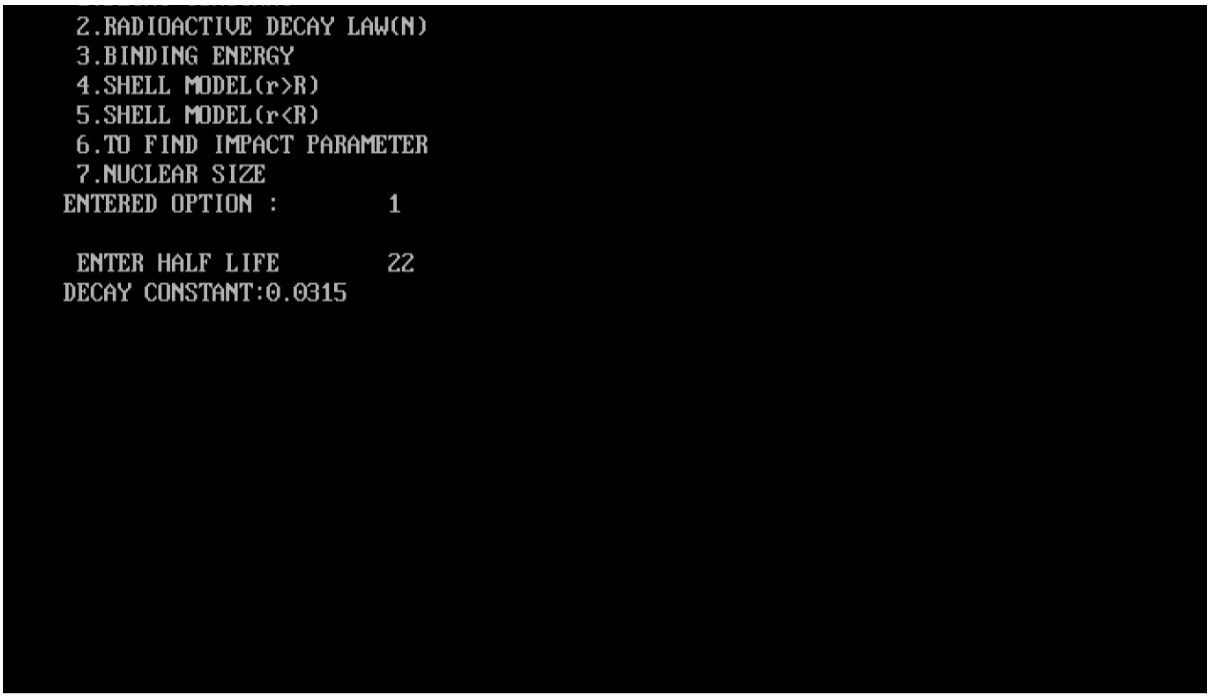
```
{int d;
cout<<"ENTER Z : " ;
   cin>>a1;
   cout <<"ENTER k:";
   cin>>a2;
   cout<<"ENTER r:";
   cin>>t;
   cout<<"ENTER r:";
   cin>>t;
  d=t/r;
  n=a1*a2*2.56/r;
  s=n*(1+.5*(1-d));
  cout<<" \ THE NUCLEAR POTENTIAL IS"<<s<<"x 10^-38";}
  break;
   case '6':
{
int z,m,u;
   cout<<"ENTER Z:" ;
   cin>>z;
   cout <<"ENTER ANGLE THETA";
   cin>>t;
   cout<<"ENTER M:";
   cin>>m;
   cout<<"ENTER U";
   cin>>u;

  n=(z*(1/tan(t/2)))/(.5*m*u);
  cout<<" \n IMPACT PARAMETER IS:"<<n;}
  break;
 case '7':
  cout <<"\n ENTER R0";
```

```
        cin>>a1;

        cout<<"ENTER MASS NUMBER";
        cin>>a2;
        r=(a1*pow(a2,1.0/3.0)) ;
        cout<<"NUCLEAR SIZE"<<r;
        break;

    default:

        cout << "\n Error! operator is not correct";
        break;
   }
   getch();
   return 0;
}
```

Output

```
Enter nuclear paramaneter you have to calculate
 1.DECAY CONSTANT
 2.RADIOACTIVE DECAY LAW(N)
 3.BINDING ENERGY
 4.SHELL MODEL(r>R)
 5.SHELL MODEL(r<R)
 6.TO FIND IMPACT PARAMETER
 7.NUCLEAR SIZE
ENTERED OPTION :
```





Results:

The theoretical and computed values were found in consistent. The above output of both binding energy and decay constant was found correct done by manual calculations.

Conclusion

In this project, we proposed to design a Nuclear Physics Calculator which will calculate some of the parameters like Nuclear Radius, Impact Parameter, Radioactive Decay, Disintegration Constant, Mass Defect And Binding Energy using C++ programming language. The design for the Nuclear Physics Calculator using the C++ is successfully compiled. The calculated values of the parameters in the programme and the manually calculated values of the parameters are equal there by the program we have developed is a success. This makes the calculation more simple and fast. These types of calculators can be used in the nuclear industries in order to make the process of calculating large data with more accuracy and without much man power. As this programme allows low level manipulation of data, the programme can be done in any small scale systems too. From this programme we learned how to build a C++ programme to calculate these parameters and also it was a great experience to do an interesting topic which will help us to reduce the effort for such calculations.

References

1. **Nuclear Physics**. By **D.C. Tayal**.
2. https://ef.engr.utk.edu/hyperphysics/hbase/Nuclear/shell.html
3. Turbo C/C++ (2nd ed.): the complete reference by Herbert Schild
4. https://www.researchgate.net/search.Search.html?type=researcher&query=nuclear%20physics