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A Study of the Energy Released by Protons in Decay

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Abstract

The energy produced by proton interaction with matter is more concentrated and the local dose is higher than that of low energy transfer linear density radiation. In this paper, the obj file of the cube of 20cm×20cm×20cm is converted into XML format and imported into python based on the idea from special to general, and the 3d spatial point source data model is established. Let the initial position of proton be (10,10,10) and all pixel points of the cube traversed by the computer generate A vector $\alpha^{'}$, $\beta^{'}$ and $\gamma^{'}$ represent the direction vector of proton momentum generated randomly. The total energy released by the proton through the cube is 4.6MeV. The Gossip algorithm is used to determine whether the pixel points are in a special three-dimensional interior such as a tetrahedron, a sphere, a cylinder, or a hexahedron formed by the material, and the total energy released by the proton in its interior is obtained.

Keywords

Proton radioactivity; Bragg curve; Spatial point cloud data; Gossip algorithm.

1. Introduction

The main application principle of proton heavy ions in the field of radioactivity is the Bragg peak. The specific ionization of protons increases with the increase of range. When the energy of protons reaches a certain value, a "Bragg peak" is formed. Later, the specific ionization decreases to zero rapidly with the increase of range. As a result, charged protons accumulate most of their energy near the Prague peak and much less when they cross it, causing a sharp drop in the dose.

However, different doses of ionizing radiation have different degrees of damage to the mechanism of organisms. Proton is a kind of high-energy line-density radiation. Compared with electron, X-ray and other low-energy line-density radiation, the energy generated by the interaction between proton and material is denser and the local dose is larger, which will cause higher relative biological effects. Therefore, it is of great significance to study the energy release of protons in materials of different shapes.

2. Consruct Spatial Point Source Datd Model

When a proton passes through a substance, it interacts with atoms in the medium, and its energy loss is approximately expressed by the Bragg formula:

$$-\frac{dE}{dl}=\frac{4\pi e^4 Z_{eff}^2 ZN}{m_e c^2\beta^2}*[\ln\frac{2m_e c^2\beta^2}{I}+\ln\frac{1}{1-\beta^2}-\beta^2-\frac{c}{z}-\frac{\delta}{2}] \quad (1)$$

dE/dl represents the stopping power of linear collision, e is the electron charge, Z is the atomic number of radioactive material with long half-life, N is the electron number density of the material, m_e is the electron resting mass, c is the speed of light in vacuum, β is the ratio of the speed of proton to the speed of light. I is the average electron ionization energy of the material, c/z is the shell correction term, $\delta/2$ is the density correction term, and Z_{eff} is the effective charge of the proton.

For high-energy region (≥1.5GeV/ nucleon), it is generally considered that the total cross section and reaction cross section have nothing to do with energy. When the energy is low, the result calculated by this formula is quite different from the actual result, so there are various modified formulas. In this paper, the image is clipped according to the graph, color image is stretched and converted into gray image by Opencv, and noise is eliminated by the operation of corrosion. Mathematical expression of corrosion operation:

$$\mathrm{dst}(x,y)=\max_{(\chi',y'):\mathrm{element}(\chi',y')\neq 0}\mathrm{src}(\chi+\chi',y+y') \quad (2)$$

The radioactive material with a long half-life is made into a cube with a side length of 20cm to simulate the track distribution of protons released by the nucleus under this shape.

When charged particles are incident on a substance, the length of the line connecting the incident point to the end point in its initial incident direction is called the range. For heavy charged particles, the direction of motion due to collisions hardly changes. And the nucleus releases protons in a random direction during the decay process. The average range of protons can be expressed as:

$$R=\int_0^{E_0}\frac{dE_M}{(dE_M/dl)} \quad (3)$$

Where R represents the average range, l represents the thickness of the material, represents the energy released by the proton, and represents the linear collision prevention power. Formula (3) can be used to calculate the range of protons in water and radioactive materials with a long half-life within the energy range of 0.01~250MeV.

Suppose that the initial position of the proton released by the nucleus is (x,y,z), and its value is all the pixels of the cube traversed by the computer. The position coordinates can be expressed as (p,q,w), α', β', and γ' are the direction vectors of the movement direction of the proton, R is the radius of the nucleus, is the Angle with the X-axis, and is the azimuth Angle. After normalization, the formula becomes (4).

$$\begin{cases}\alpha'=\cos\theta\cos\varphi\\ \beta'=\cos\theta\sin\varphi\\ \gamma'=\sin\theta\end{cases} \quad (4)$$

Therefore, the distance between the initial position of the proton and its vector direction and the intersection point on the surface of the cube is obtained, namely the proton's range:

$$d=\sqrt{(x-\alpha^{'})^{2}+(y-\beta^{'})^{2}+(z-\gamma^{'})^{2}} \quad (5)$$

Let represent the vector from the initial position of the proton to the pixel of the cube. When the cosine of the Angle between $m=(x-p, y-q, z-w)$ and $n=(\alpha^{'},\beta^{'},\gamma^{'})$ approaches 1, the distance between the pixel and the initial position of the particle is considered to be the range of the proton in the cube. Therefore, the pixel can replace the general level in the coordinate range of the substance.

Table 1. Model test

Initial proton position	Cube surface pixel	Range	Cosine of the Angle between m and n
(10,10,10)	(13,12,0)	10.63	0.9987
(10,10,10)	(9,10,20)	10.05	0.9980
(10,10,10)	(0,11,4)	11.70	0.9992
(10,10,10)	(0,13,3)	12.57	0.9994
(10,10,10)	(15,16,20)	12.69	0.9999
(10,10,10)	(0,14,5)	11.87	0.9992

The coordinates of pixel points (10,10,10) are selected as the initial position of a proton. After several iterations and traversal, the cosine values of the Angle between and are all calculated to be greater than 99% and close to 1, so the authenticity and reliability of the model are proved. Convert the obj file in the format of 3D model file into XML format and import it into python to establish the 3D point source spatial data model, as shown in Figure 1:

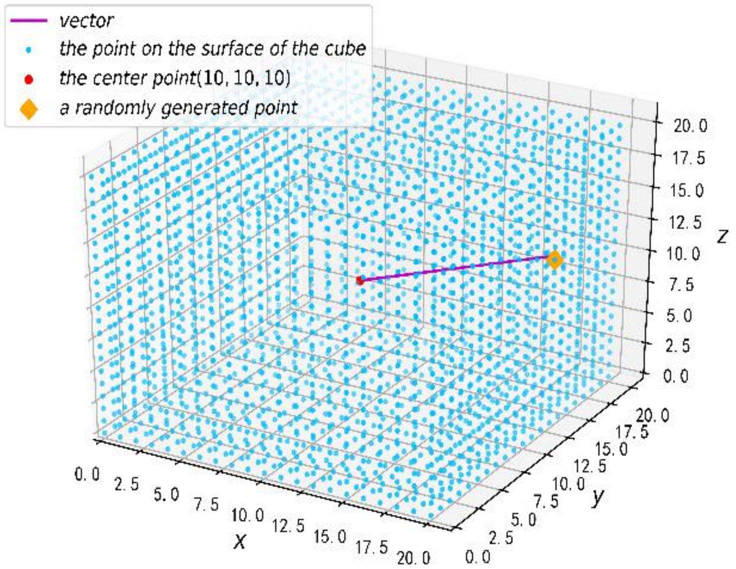

Figure 1. Cube spatial point cloud data

The range value is substituted into the Bragg curve expression to further calculate the energy value released by the proton at this position. Similarly, the energy released by other protons can be calculated. When the proton passes through the positive square, the total energy released in the positive square can be obtained as follows: $E_{total}=\sum_{i=1}^{n}E_{Mi}$

Formula and curve of total energy released by proton with range:

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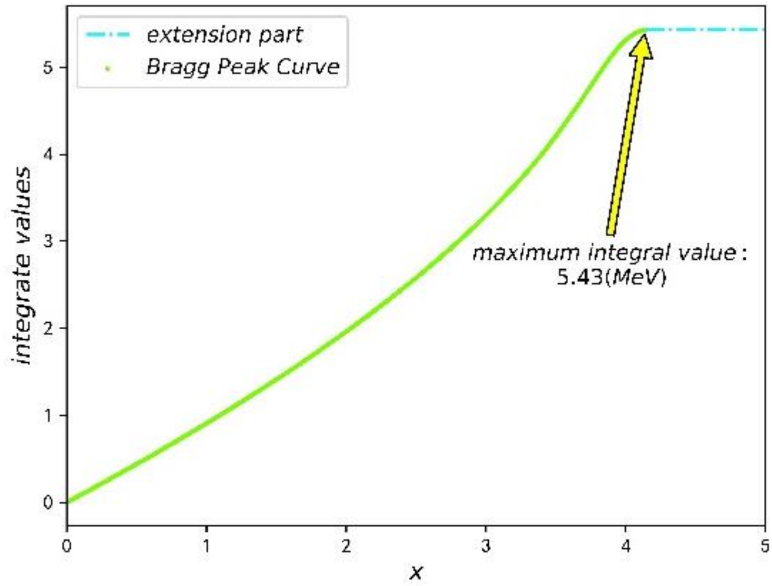


Figure 2. Energy integral curve

Formula and curve of total energy released by proton with range:

$$E_{total} = 4*10^{-8} l^3 - 7*10^{-6} l^2 + 0.0097 l - 0.0221 \tag{6}$$

Without considering the pixel points of the six faces of the cube, the energy released by each pixel point inside the cube is calculated by using the relation between proton range and energy through python and arranged as shown in Table 2:

Table 2. The amount of energy released by a proton at different ranges

Pixel position	Energy released by protons at each pixel /MeV
(1,1,1)	1.670032
(1,1,2)	4.148382
(1,1,3)	5.43
(1,1,4)	5.43
	5.43
(1,1,5)	5.43
……	……
(19,19,19)	5.43
Average	4.6

In conclusion, nuclear decay release protons are in a different direction, if the density of the material, length of 20 cm cubes, through to the cube on the traversal of each pixel is, it is concluded that the distance between the protons and pixel is the range of protons through the cube, to bring to fitting the integral formula of range, it is concluded that the proton, the total energy released in the cube is 4.6 MeV.

3. Simulation Based on Gossip Limit Algorithm

The discriminating algorithm of the eight diagrams limit: the eight diagrams limit algorithm is mainly used to judge the inner points of the three-dimensional graph. First, its 3d point cloud array can be obtained through the graph file. The point in question is the intersection of the contour data and a point inside the cube much larger than the graph. As is known to all, the three dimensional space can be divided into the eight diagrams, when the target is in close proximity to the geometry surface, will produce the tangent plane, the target point and the geometry of any point on the surface of the vector are on one side of the tangent plane of origin under rectangular coordinate system according to the space plane, at the side of the plane there is at least one without this point in the plane of the hexagrams limit, so be sure to meet in the eight diagrams produced in the limit of at least one without vector.

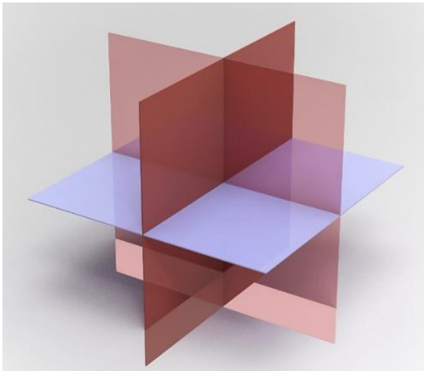
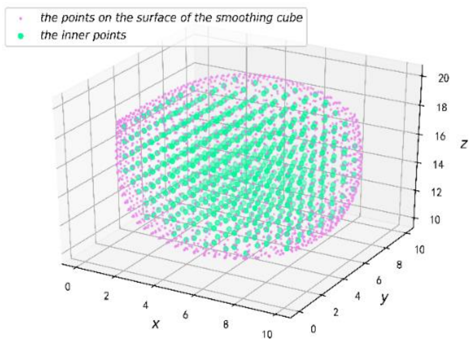
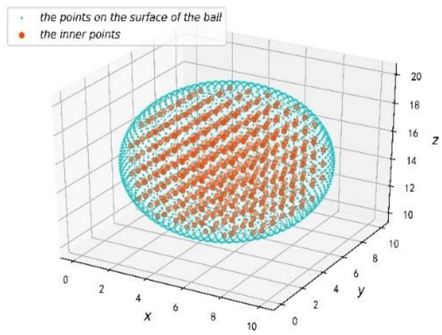


Figure 3. Diagram of space division of eight diagrams

Focusing on the idea from special to general, this paper extracts effective pixel points from a large number of special solids such as tetrahedron, sphere, cylinder and hexahedron, and uses python to simulate the variation of the range and energy of protons when they pass through these graphs. Then the non-sample is carried out to obtain the calorific value obtained from the training set and the test set.



Smooth cube: 4.559 MeV



A sphere: 5.374 MeV

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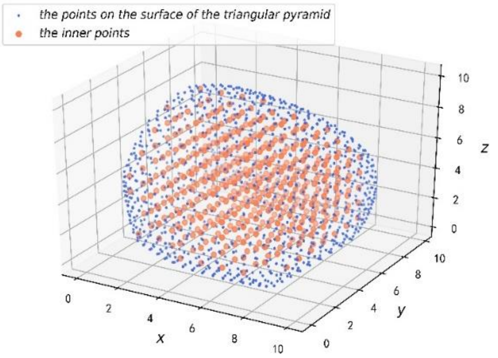
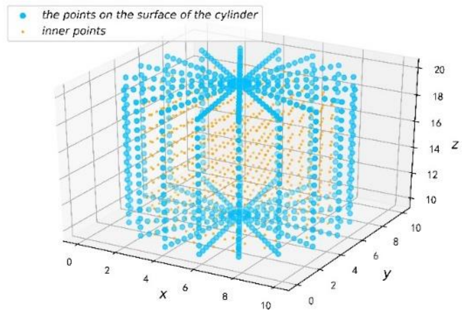
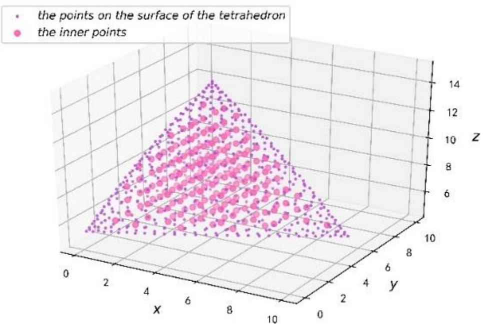


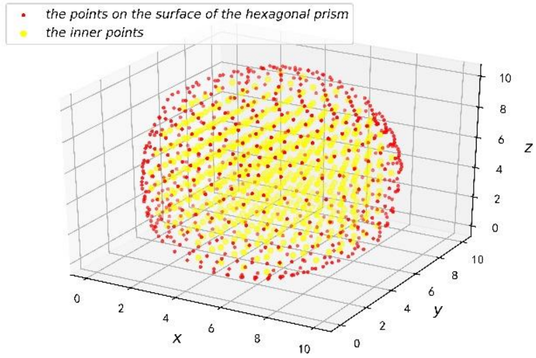
Triangular pyramid: 4.510MeV



Cylinder: 5.039 MeV



Tetrahedron: 4.077MeV



Six prism: 4.525MeV

Figure 4. Training set spatial point source data graph

4. Conclusion

Applying from the special to the general idea, the equal quality materials are made into cubes and spheres respectively. The obj file in the 3D model file format is converted into xml format and imported into python, and the 3D point source data is extracted as the cube and the sphere. The position coordinates of the point are based on a large amount of data, which provides great convenience for the release of the total energy of the proton and saves a lot of time. The simulation results are shown: The total energy released by a proton in a smooth cube, a sphere, a triangular pyramid, a cylinder, a tetrahedron and a six prism is 4.559 MeV, 5.374 MeV, 4.510MeV, 5.039 MeV, 4.077MeV, 4.525MeV.

References

[1] Gao Liugang. Lateral scattering and dose compensation of proton radiotherapy [D]. Nanjing University, 2014.

[2] Xie Tianwu. Study on rat radiation dosimetry based on Monte Carlo method [D]. Huazhong University of Science and Technology, 2011.

[3] Zhao Penglei. Research and implementation of binary function similarity detection algorithm based on graph neural network [D]. Zhejiang University, 2019.

[4] Hu Yankang, Fan Xin, Yu Letian, Luo Zhongyu. Face Super-Reconstruction Reconstruction Based on Graph Neural Network Regression[J]. Journal of Software, 2018, 29(04): 914-925.

[5] Wang Yunnan. Simulation of DNA strand breakage induced by proton radiation [D]. Harbin Engineering University, 2017.

[6] Dong Jianmin. Study on the symmetry energy of nuclear matter, the structure of neutron stars and the properties of superheavy nuclei [D]. Lanzhou University, 2012.

[7] Wang Jiamei. The alpha decay of the nucleus and its competition with proton radiation [D]. Lanzhou University, 2014.

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[8] Li Xingqi. Irradiation effect and damage mechanism of charged particles in star bipolar devices [D]. Harbin Institute of Technology, 2010.

[9] Zhang Jianian. Analysis of the internal structure model of the atomic nucleus[J]. Science and Technology, Enterprise (2015): 227-231.