The Liquid Drop Model: An Interactive Exploration

Alejandro Romero-Ros

January 8, 2026

Abstract

This document provides an overview of the Liquid Drop Model (LDM) of the atomic nucleus and details the interactive activities designed to explore its concepts. It also includes a step-by-step guide for setting up and running the project's local server to visualize the results of the student activities.

Contents

1 Introduction to the Liquid Drop Model

What holds an atomic nucleus together? The **binding energy** of a nucleus is the answer: it measures the energy gained by assembling neutrons and protons to form a nucleus. For instance, if you take the mass of 8 protons and 6 neutrons and compare it to the experimentally measured mass of an ^{14}O (oxygen-14) nucleus, you'll find that the nucleus is *lighter* than its parts. This "missing" mass has been converted into a large amount of energy, as described by Einstein's famous formula, $E = mc^2$. This energy is the binding energy.

While experiments can measure the binding energy of thousands of nuclei, scientists also want to be able to predict these properties without an experiment. This is where scientific models come in. The **Liquid Drop Model**, first conceived by nuclear theorists in the 1930s, is one of the simplest and most successful models for this purpose. It treats the nucleus as if it were a drop of incompressible liquid, like a tiny water balloon. This analogy works surprisingly well because the strong nuclear force that binds nucleons together is very short-range, much like the forces between molecules in a liquid.

The model allows us to estimate the average binding energy per nucleon (BE/A), a key measure of a nucleus's stability, using the **Semi-Empirical Mass Formula (SEMF)**:

$$\frac{BE}{A} = a_v - a_s A^{-1/3} - a_c \frac{Z(Z-1)}{A^{4/3}} - a_a \frac{(A-2Z)^2}{A^2} + \frac{a_p}{A} \tag{1}$$

Where A is the total number of nucleons (protons + neutrons) and Z is the number of protons. Each term represents the contribution per nucleon from a different physical effect:

1. **Volume Term (a_v):** This term provides a constant positive amount to the binding energy. It comes from the idea that each nucleon only interacts with its immediate neighbours due to the short range of the nuclear force.

2. **Surface Term ($-a_s A^{-1/3}$):** This term has a minus sign because nucleons on the surface have fewer neighbours to interact with, making them less tightly bound. This is similar to surface tension in a real liquid drop.

3. **Coulomb Term ($-a_c \frac{Z(Z-1)}{A^{4/3}}$):** This accounts for the electrostatic repulsion between positively charged protons. This repulsive force reduces the binding energy and explains why large, stable nuclei need more neutrons than protons to add "binding" without adding more repulsion.

4. **Asymmetry Term ($-a_a \frac{(A-2Z)^2}{A^2}$):** The nucleus is most stable when the number of neutrons and protons is roughly equal ($N \approx Z$). This term introduces an energy penalty for moving away from this symmetry.

5. **Pairing Term ($\frac{a_p}{A}$):** A quantum mechanical effect where nuclei with an even number of protons and/or an even number of neutrons are systematically more stable than those with odd numbers. The pairing parameter, a_p, sets the magnitude of this correction, which is positive for even-even nuclei, negative for odd-odd nuclei, and zero for nuclei with an odd mass number.

Not only does this formula help us understand the properties of the thousands of known nuclei, nuclear stability and phenomena like nuclear fission, but it also allows us to predict the properties of nuclei we have not yet discovered and even to understand some properties of incredibly dense objects like neutron stars. It's important to remember that this is a scientific model; it's a powerful tool, but it can always be improved or replaced by new data or a new groundbreaking theory. Perhaps you will be the one to improve it!

2 Description of Activities

The project includes two main activities designed to let you interactively explore the concepts of the Liquid Drop Model. For each activity, you can select any element from the periodic table and work with its isotope data, which is taken from the official Atomic Mass Data Center.

2.1 Activity 1: Fitting the Liquid Drop Model

This activity is divided into five parts. The main goal is to understand how the Liquid Drop Model parameters $(a_v, a_s, a_c, a_a, a_p)$ relate to real-world data. You will use sliders to adjust the values of these parameters and try to fit the theoretical model to the experimental data for a chosen element.

Two plots will guide your work:

- **Upper Plot:** This shows the binding energy per nucleon (BE/A) versus the mass number (A). The blue dots are the real experimental data, and the red line is the theoretical value from the LDM formula using the parameters you set with the sliders.
- **Lower Plot:** This shows the difference (the error) between the experimental data and your theoretical fit.

Your objective is to adjust the sliders to make the red line in the upper plot match the blue dots as closely as possible. This is equivalent to making the error in the lower plot as close to zero as you can for all the isotopes. Through the 5 sub-activities, you will determine the best-fit values for the LDM parameters in a guided way.

2.2 Activity 2: Predicting the Heaviest Isotope

This two-part activity challenges you to use the LDM parameters you found in Activity 1 to make a prediction. An isotope can only exist if its binding energy is positive (BE/A > 0). If the binding energy is zero or negative, the nucleus would spontaneously fall apart.

Your goal is to use the model to answer the question: **what is the most massive isotope of a given element that can possibly exist?**

You will again use sliders, this time to explore how uncertainties in the LDM parameters affect your prediction for the heaviest possible isotope. This will give you a range of possible mass numbers (A) for the limit of nuclear existence.

3 Connecting to the Server: A Guide for Teachers and Students

To allow students' results to be collected and viewed centrally, the project uses a simple client-server setup. The teacher or presenter runs the `server_gui` application, and each student uses the `main_window` application to connect to it.

The applications are available as pre-built executables for Windows and Linux, which can be downloaded from the project's repository. There is no version for macOS at this time.

3.1 For the Teacher: Running the Server

As the teacher or presenter, your role is to host the server that students will connect to.

1. Download and run the `server_gui` application for your operating system (e.g., `server_gui.exe` for Windows).
2. A control window will appear. Simply click the **Start Server** button.
3. Once the server starts, a **Server URL** will be displayed in the window (e.g., `http://192.168.1.100:5001`). This is the address you need to share with your students. You can use the **Copy URL** button for convenience.
4. As students connect and submit their data from the activities, their messages and results will appear in the "Received Messages" log window.
5. When the session is over, simply click the **Stop Server** button to shut down the server.

3.2 For the Student: Connecting to the Activity

As a student, you will connect your application to the teacher's server to submit your results.

1. Download and run the `main_window` application for your operating system (e.g., `main_window.exe` for Windows). This is the main program containing the activities.
2. In the application, navigate to the **Logs** tab.
3. Type the **Server URL** provided by your teacher into the text field at the top. If you have connected before, the application may remember the last used URL.
4. Click the **Connect** button.
5. The "Connection status" log should update to show a "Connected" message.
6. That's it! Now, as you complete parts of the activities, you can click the **Send** button to send your results to the teacher's server.

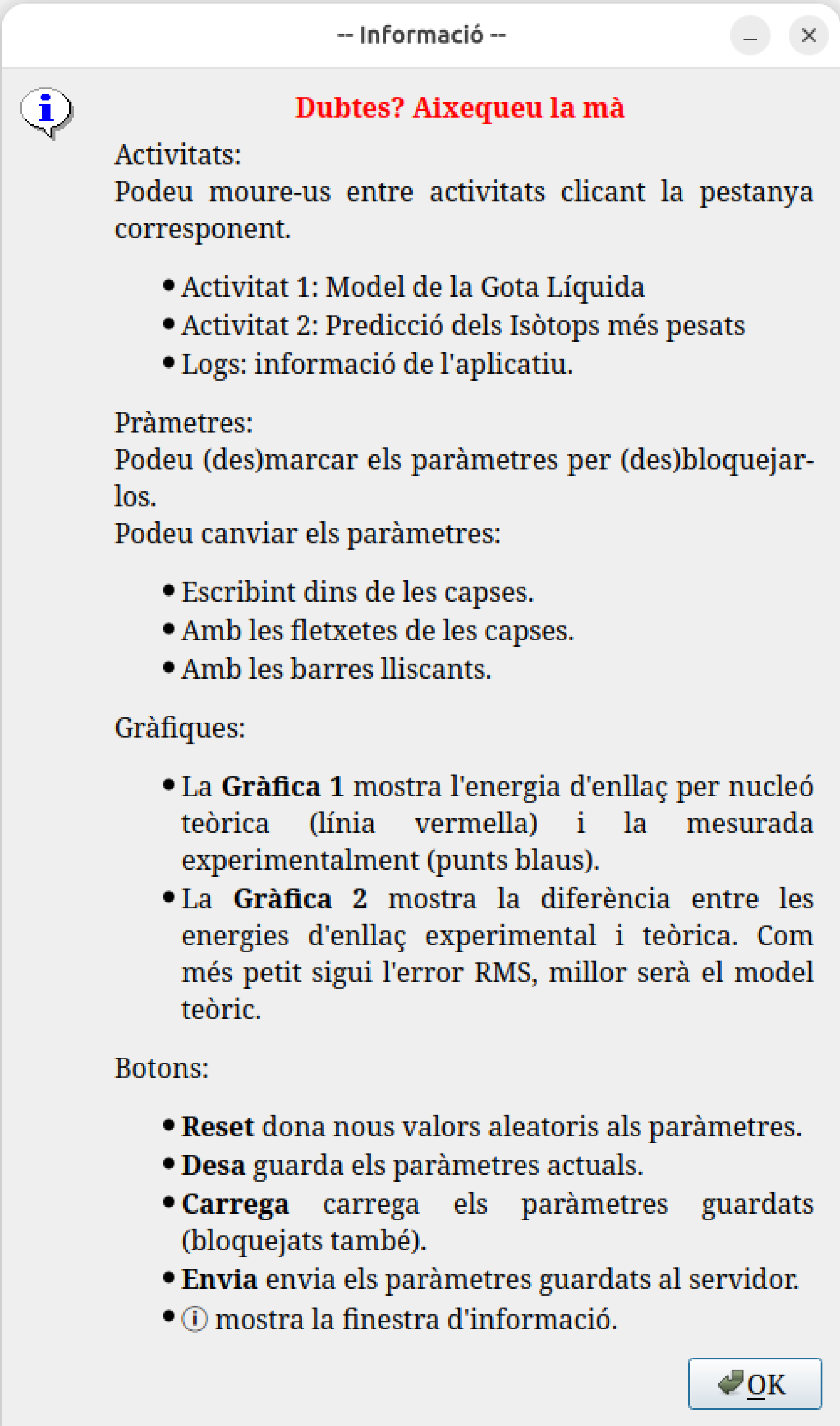

Figure 1: A visual representation of the different contributions to the binding energy in the Liquid Drop Model.

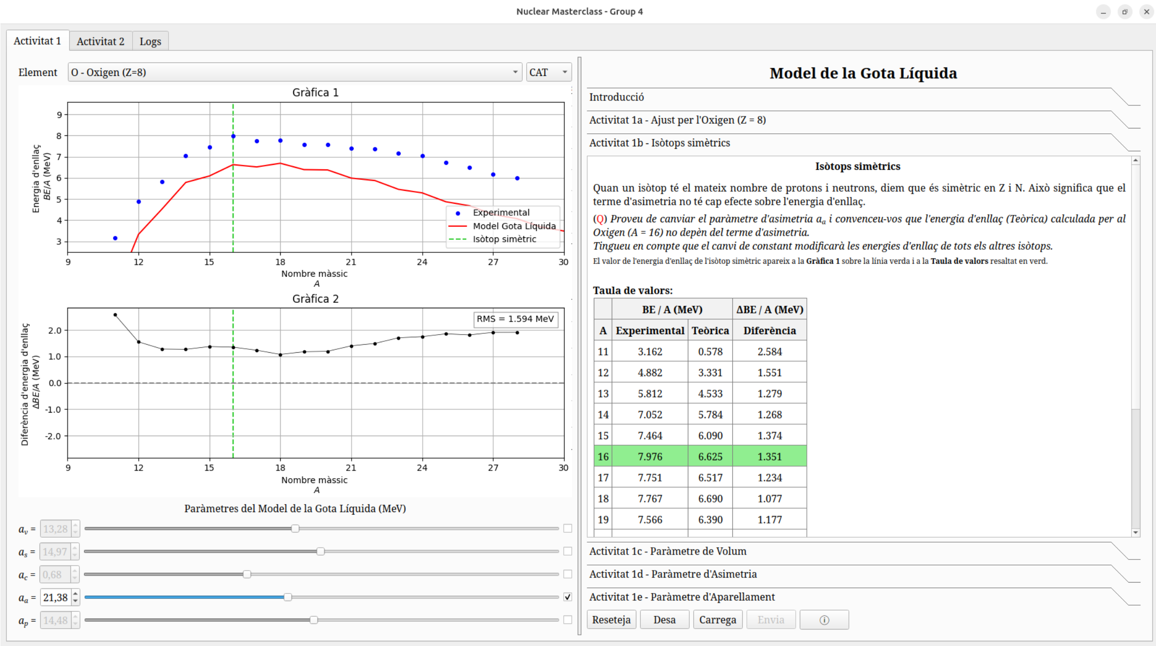

Figure 2: The interface for Activity 1. Students use the sliders on the left to match the theoretical model (red line) to the experimental data (blue dots).

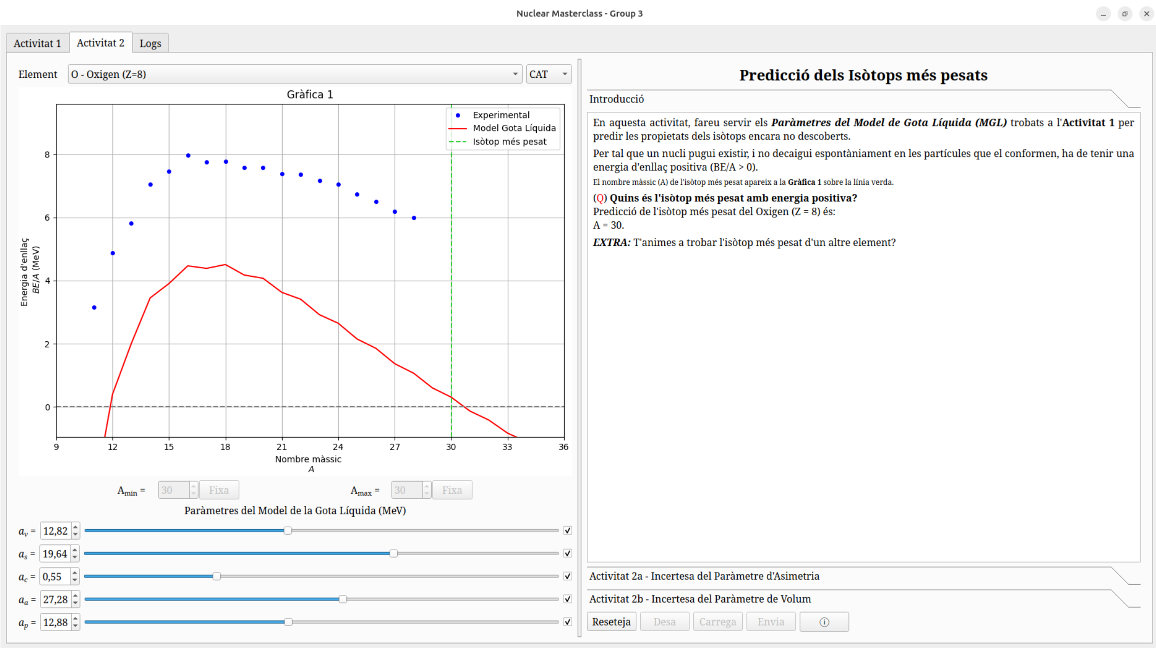

Figure 3: The interface for Activity 2, used to explore the limits of nuclear stability and predict the heaviest possible isotopes.