

## Research on Virtual Simulation Software for Measuring Liquid Viscosity Coefficient by Falling Ball Method Based on COMSOL

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**Abstract:** This paper is based on COMSOL Multiphysics platform developed an support user-defined liquid coefficient of viscosity measurement software, primarily based on university physics experiment, falling ball method to measure liquid viscosity coefficient, using COMSOL own APP development, establish a physical scale model, set up the corresponding physical fields, simulates the ball movement in the liquid in a reliable way, the simulation results highly consistent with the experimental results. The software also supports user-defined parameters, such as object properties, boundary conditions, ambient temperature and other functions. The software has a high degree of visualization, which can reflect the falling speed and trajectory of the ball in the liquid environment in real time with multiple Windows and animations. On the one hand, this software can be used as an auxiliary means of basic physics experiment teaching in various universities and an experimental platform for online courses. On the other hand, it can be used as a means of measuring liquid viscosity coefficient for researchers, which can be used as a pre-experiment to save the cost of experimental materials and time.

### 1. Introduction

In the experiment of measuring the liquid viscosity coefficient by the falling ball method in the university general experiment, the liquid to be measured must be placed in a container, so the condition of infinite depth and width cannot be achieved. The influence of the inner diameter of the container  $D$  and the height of the liquid column  $H$  should be considered in the experiment.

The experimental results show that if the ball falls along the central axis, the expression formula of the viscosity coefficient of the liquid satisfies the following equation [1]:

$$\eta = \frac{(\rho - \rho')gd^2t}{18l(1 + 2.4\frac{d}{D})(1 + 1.6\frac{d}{H})} \quad (1)$$

Where  $\rho'$  is the density of the pellet material,  $\rho$  is the density of the liquid,  $l$  is the distance of the pellet falling at uniform speed, and  $t$  is the time taken by the pellet falling distance  $l$ .

In the actual experiment, various factors make the experimental operation cannot meet the requirements of the experiment. Firstly, the experimental conditions of infinite width and depth cannot be provided experimentally, so the theoretical formula needs to be revised. Secondly, the experiment requires that the temperature of the liquid be uniform. In fact, the temperature of the liquid in the container is gradient. Thirdly, students cannot determine when the small steel ball starts to move at a uniform speed in the practical experiment, and the observation of its speed change is not intuitive [2][3]. Finally, it is difficult for students to understand the application conditions and application scope of different correction laws. In addition to the above-mentioned problems, other experimental subjects and experimental conditions are limited, which makes it difficult for students to further explore the experiment. However, these conditions which cannot be realized or are difficult to be realized in the actual experiment can be realized in our simulation.

Based on the above factors, we use COMSOL Multiphysics software to develop the virtual simulation experimental software for measuring the liquid viscosity coefficient with the falling ball method, to assist teaching, for students to explore and divergent thinking after class.

At the same time, it also provides a good platform for scientific research personnel to explore the relevant pre-experiment.

## **2. COMSOL modeling and APP development**

In COMSOL Multiphysics, we simulate the experimental process of measuring liquid viscosity coefficient by falling ball method. Based on the finite element method, COMSOL realizes the simulation of real physical phenomena by solving partial differential equations (single field) or partial differential equations (multiple fields).

First, we will define the parameters of our simulation model under the global definition tree, where the parameters of the cylinder and the parameters of the released steel ball are consistent with the actual experiment. We set up a three-dimensional component, set up a hollow cylinder tube containing glycerine liquid under the geometric tree, set up a steel ball to release from the liquid surface at no speed, and then add materials to the component. The hollow cylinder tube is made of glass, and the liquid material inside is glycerine. We choose the fluid flow tracking module in the physical field, where the particles to be tracked are steel balls moving in the liquid. Adding gravity and drag. As for the drag law, COMSOL provides us with Stokes Law, NS equation, OSEEN correction and other six kinds.

We initially chose OSEEN correction. After the construction of the simulated physical field, we choose the grid for subdivision. The calculation of the COMSOL finite element will be based on the grid subdivision. The physical field is basically constructed here. Next, we will construct the study, selecting the transient study. In the traditional finite element analysis, the transient study selects and sets the solver and obtains the solution of the equation in a reasonable computation time. We will show the velocity of steel ball with time in the one-dimensional drawing group. The final velocity of a steel ball moving at a uniform speed was found in the one-dimensional drawing set and the corresponding expression for calculating the viscosity coefficient of glycerol was substituted. You can get the results of the experiment. We used the built-in APP developer in COMSOL to compile the model. At this point, the software development is complete.

When users conduct experiments with our virtual simulation experimental software, interface 1 will appear first, as shown in Figure 2.1.

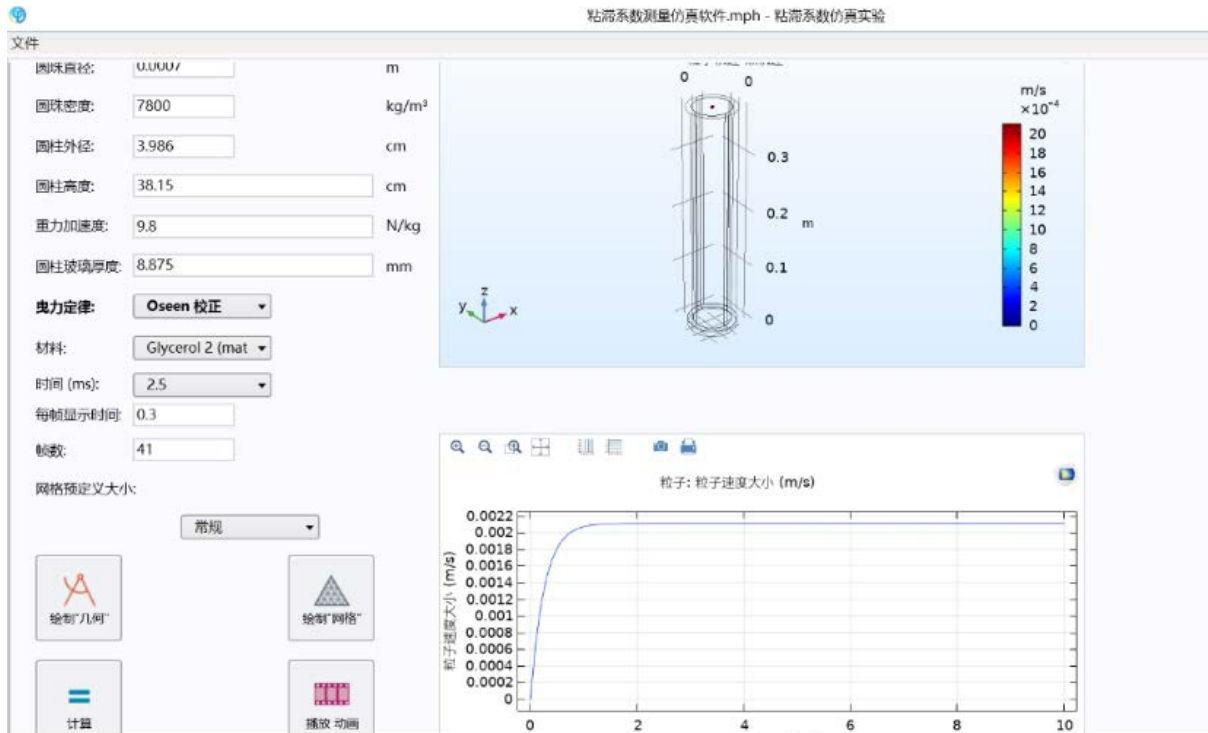


Fig. 1 Measurement of liquid viscosity coefficient by falling ball method software interface 1

In Figure 1, we can see that there are a series of adjustable parameters on the left, such as experimental temperature, sphere diameter, sphere density, etc. The user inputs the parameters according to the real values measured in the actual experiment. After inputting parameters, the appropriate drag law can be selected, here we take OSCEEN correction as an example. The liquid material was glycerine. The motion process of steel ball from 100 milliseconds [4] after release was studied. Click Draw Geometry, Draw Grid, and Calculate in turn. Waiting for the running result of the virtual simulation experiment software, and the curve of the speed of the steel ball with time will be displayed after the calculation is completed. We can clearly see that the steel ball starts from the fall and accelerates with a decreasing acceleration. After a very short time interval, the steel ball starts to move at a constant speed. We only need to know the uniform motion value of the steel ball, that is, the final velocity value, and then substitute all user-defined parameters and the final velocity value obtained from the virtual simulation experiment software into the corresponding expression of the viscosity coefficient for calculation. The viscosity coefficient of glycerol under this user-defined condition can be obtained. By changing the temperature, the movement law of steel ball in glycerol can be simulated at different temperatures, and then the viscosity coefficient of glycerol at different temperatures can be obtained. This is the whole process of simulating the actual experiment. In addition, click the animation, you can intuitively see the ball's falling motion picture. If users still want to explore more applicable conditions of drag law, they can change the drag law at any time, replace OSEEN correction with N-S equation, and continue to calculate the motion law of steel ball in liquid. In addition, in the actual experiment, we are unlikely to change the liquid material at will. In the simulation experiment, these conditions can be changed at any time. Here, for example, the user can easily replace the original glycerol with gasoline. Click Calculate and we can see that the movement law of steel ball in gasoline is different from that in glycerol.

Then enter the second interface of virtual simulation experiment software. This is shown in Figure 2.2. We can simulate the movement of steel balls in cylindrical containers of different diameters. Here we choose three cylindrical pipe diameters as examples to illustrate the influence of cylindrical pipe diameters on the motion law of steel balls. After user-defined parameters, click "Draw Geometry", "Draw Grid" and "Calculate" successively. Observe the movement rules of the balls under the three pipe diameters. Let's test the results. The results show that the movement law of steel ball is different under different pipe diameters. Comparing the velocity curves of the ball movement under three

different pipe diameters, we found that the steel ball in the container with relatively small pipe diameters has a relatively long acceleration process and a relatively high finishing speed. In the case of relatively large pipe diameter, the accelerating process of steel ball is shorter, and the finishing speed is smaller. If the viscosity coefficient of glycerol is calculated at these three different velocities, the three viscosity coefficients are different. However, the material and temperature of the liquid are the same, so the viscosity coefficient should also be the same. Therefore, the calculation of the model does not conform to the boundary conditions of the corresponding drag law.

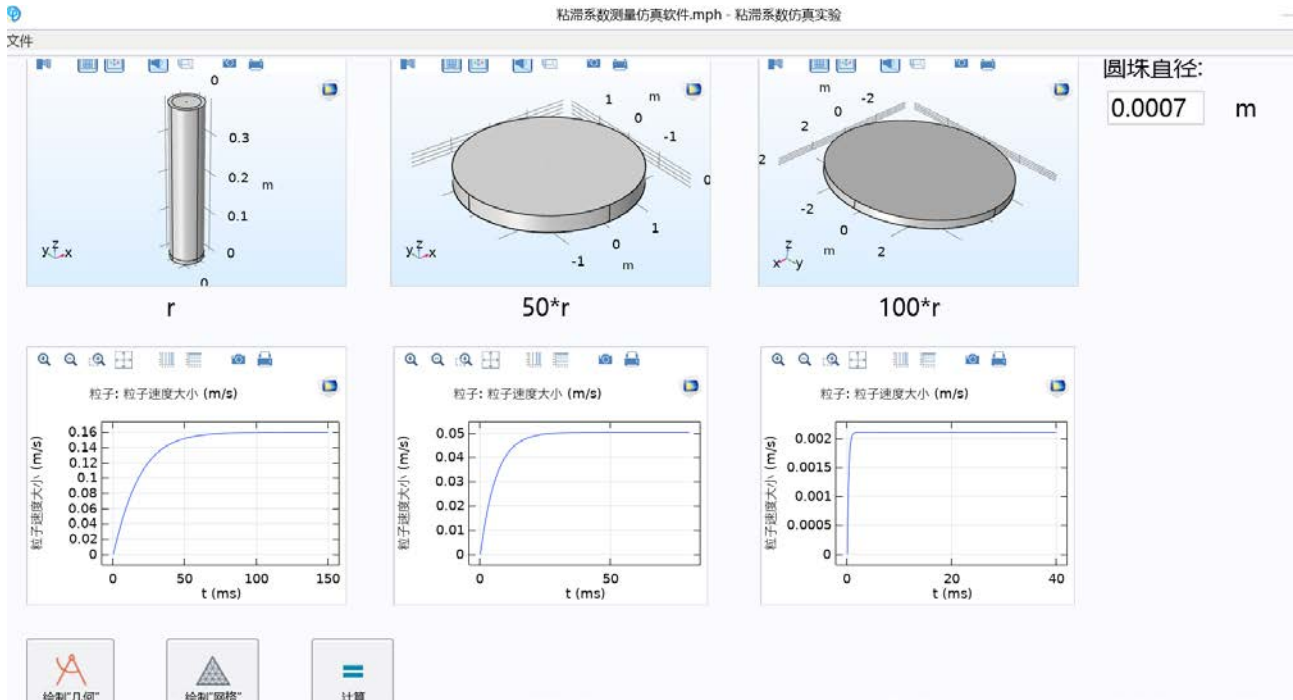


Fig. 2 Software interface II for measuring liquid viscosity coefficient by falling ball method

Next, we open the third form, as shown in Figure 2. Here, we can simulate the movement of steel balls with different diameters. Here we choose three steel balls with diameters of  $r$ ,  $50r$ ,  $100r$  as examples to illustrate the influence of steel ball diameters on the movement law of steel balls. After user-defined parameters, click Draw Geometry successively, click Calculate, and wait for the result. The results show that the movement rules of steel balls with different diameters are different. By comparing the velocity curves of three steel balls with different diameters, we find that in the case of relatively small diameters, the acceleration process of the steel balls is relatively short, and the finishing velocity is relatively small. In the case of relatively large diameter, the acceleration process of steel ball is longer, and the finishing speed is higher. If the viscosity coefficient is calculated according to these three different ending velocities, the three viscosity coefficients are also different. However, the material and temperature of the liquid are the same, so the viscosity coefficient should also be the same. Therefore, the larger diameter of the steel ball does not conform to our OSCEEN corrected drag law.

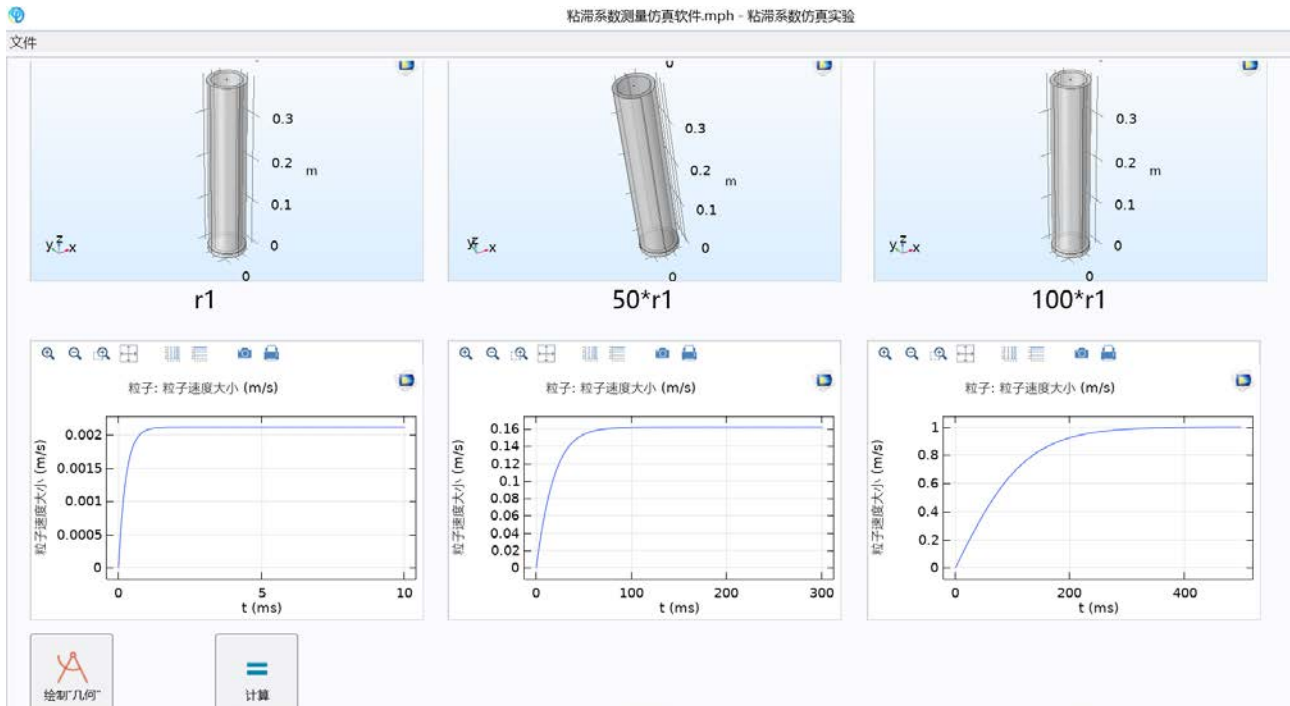


Fig. 3 Measurement of Liquid Viscosity by Falling Ball Method Software Interface III

Finally, in Form 4, we explain the functions of the first three forms so users can use them.

We compile the virtual simulation experiment software into executable files. When users use our virtual simulation experiment software to conduct virtual simulation experiment, they only need to adjust the parameters to simulate the actual experiment situation.

### 3. The function of viscosity coefficient measurement software

The software of measuring liquid viscosity by falling ball method developed by us can explore the variation law of liquid viscosity coefficient at different temperatures. The motion law of the ball under different drag laws can be explored and the correction of the viscosity coefficient can be understood. The viscosity coefficient of different liquid materials can be explored. A case where infinite extensibility can be achieved; The viscosity coefficient can be obtained by exploring the motion law of balls with different diameters in the liquid. The viscosity coefficient can be obtained by exploring the motion law of the ball in the liquid under different pipe diameters. Support user customization to meet individual needs; Combined with the real experiment to help students understand the experiment; The process of showing clearly and intuitively that physical conditions cannot be shown; To provide researchers with a wealth of experimental objects and experimental environment.

### 4. Software reliability testing

We currently developed software version 1.0 has been completely can realize most of the functions, such as measuring the viscous coefficient of glycerol with temperature changes in the relationship, use this project members to develop "the coefficient of viscosity measurement virtual simulation software" simulation, we respectively set temperature 299.95 K, 303.35 K, 308.65 K, 313.45 K, 323.15 K, 327.55 K, we get a small steel ball speed change curve in the glycerol as shown in figure 4.1 and 4.6.

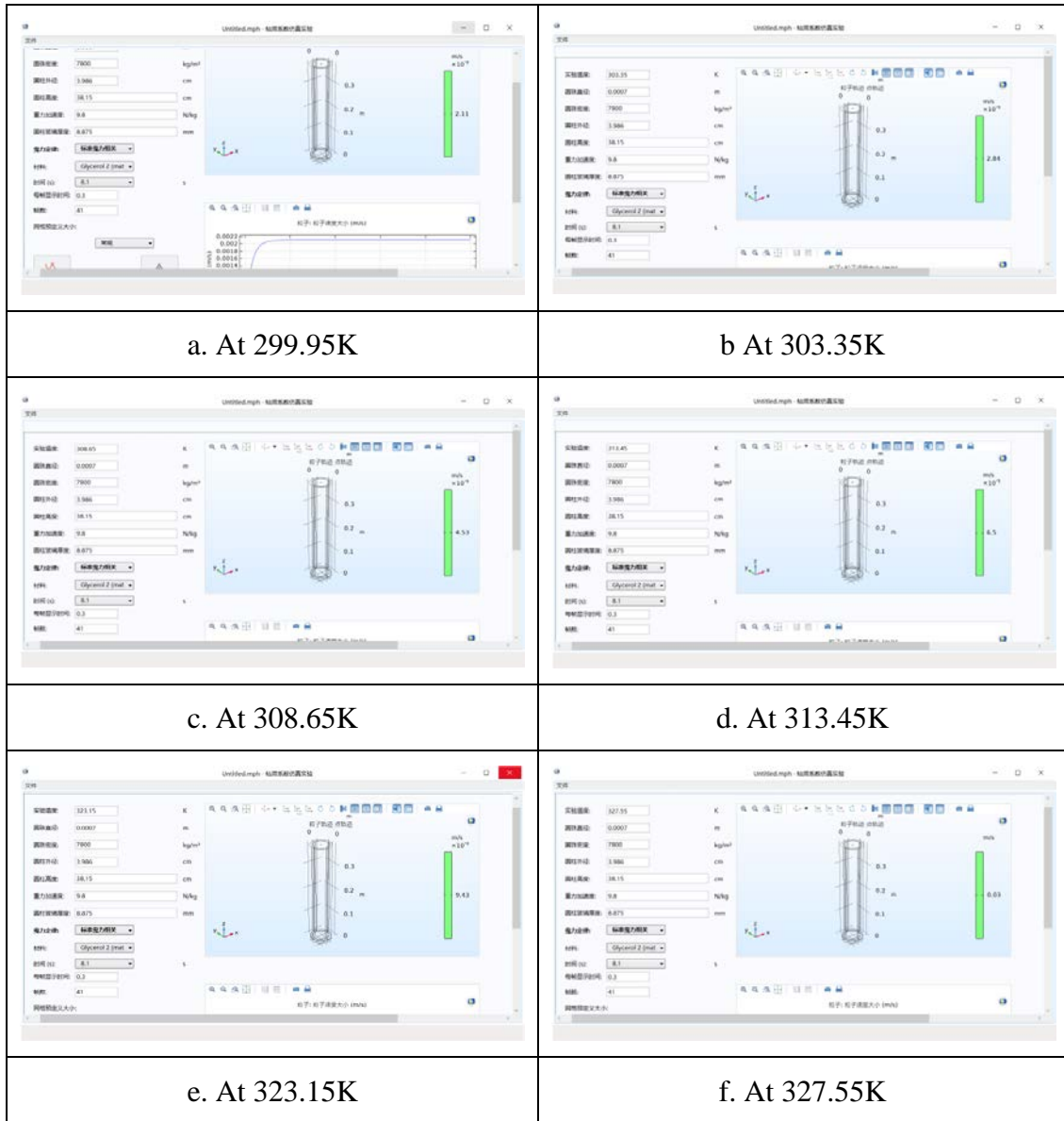


Fig. 4. Simulation results of velocity variation of small steel ball under different temperature conditions

According to the values of each ending velocity (constant velocity motion value), the relationship between the viscosity coefficient and velocity was used to calculate the results. Finally, the comparison results between the experimental, simulation and empirical values were obtained as shown in the table below:

Table 4. Comparison of virtual software simulation results and real experimental results

Temperature/k	The simulation value/Pa*s	Experiment value/Pa*s	The error compared to the experimental value /%	empirical value/Pa*s	The error compared to the empirical value /%
299.95	0.768	0.686	10.8	0.807	4.74
303.35	0.571	0.515	9.84	0.597	4.34
308.65	0.358	0.325	9.15	0.378	5.33
313.45	0.250	0.220	11.8	0.254	1.56
323.15	0.172	0.154	10.7	0.117	46.9
327.55	0.0542	0.0593	9.50	0.0839	35.4

The empirical value is given by the empirical formula  $\eta = 1.748 * 10^{-12} \exp(8056 / T)$  (the unit of  $T$  is  $K$ , the unit of  $T$  is  $Pa * s$ ), which is applicable in the room temperature zone.

By comparing with the simulation values, we can find that the two accord perfectly in the normal temperature region (299.95K, 303.35K, 308.65K, 313.45K), and have a large error in the high temperature region (323.15K, 327.55K). Compared with the experimental value, the simulation value in the normal temperature area is closer to our empirical value, which indicates the accuracy of the simulation experiment and the reliability of our model. At present, the software developed by the project team members has basically met the needs of auxiliary teaching.

## **5. Software promotion and application**

Our virtual simulation experiment software can reflect the physical laws of real experiment, with good participation, simulation, and openness.

Not only can be implemented at any time change law of temperature, the drag force, the liquid material, change the parameters of cylinder and steel ball, realize the infinite variety of custom functions such as extensive, can also be combined with physical experiment teaching, help students understand all correction and nearly thought and process, and, more importantly, can clear and intuitive cannot demonstrate the process of the physical experiment and the experimental results.

At the same time, abundant experimental subjects and experimental environments are provided to carry out more open experiments.

## **References**

- [1] Mao Aihua, Wu E, Cai Lu. University Physics Experiment,2018,31(03):101-104. (in Chinese)
- [2] Cheng Yumei. Study on measuring liquid viscosity coefficient by falling ball method [J]. Science and Technology Innovation Herald,2018,15(25):107+109.
- [3] Wang Hengtong, Xu Chunyuan, Dang Lei. Theoretical Calculation of Liquid Viscosity Coefficient at Different Temperatures [J]. Experimental Science and Technology,2017,15(05):20-23.
- [4] Li Yaya, Wang Guohua, Ke Sha, Hu Yaya. Detail exploration of measuring liquid viscosity coefficient by falling ball method [J]. Shandong Industrial Technology,2017(15):261-262.