



Teaching Design of Senior High School Physical Logic Gate Circuit

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Abstract

In the section on “Logic Circuit” in senior high school physics, both textbooks and existing teaching research on this aspect are more focused on the principle analysis of logic circuit structure. Although a few studies involve the making of relevant teaching instruments, the layout and wiring of the device are not standardized, and its operational compatibility is low, so students do not have a comprehensive understanding of this aspect of knowledge. In order to solve this problem, I use the relevant knowledge of electronic technology to make a simple “AND” gate circuit to assist the explanation of the logic circuit, the effect of teaching and demonstration is good. In the meantime, it also provides a kind of idea of self-made teaching instruments for teachers when explaining the relevant content.

Subject Areas

Senior High School Physics

Keywords

Senior High School Physics, Logic Circuit, Electronic Technology, “AND” Gate, “OR” Gate, Teaching Instruments Making

1. Introduction

For the teaching exploration of “Senior High School Physics Gate Circuit” and “Senior High School Physics Logic Circuit”, one focuses on the analysis of circuit principle. For example, Teacher Xuequan Luo has made a detailed analysis and summary about the application of the middle school physics logic gate circuit [1]; Teacher Shuru Fang applied the limit thinking to the relevant solution of the gate circuit, making the problem become simplified [2]; Xiang Bao and Zhenfeng Dou took the typical Burglary Alarm Kit and automatic control street lamp

circuit in life as an example for the detailed analysis [3] [4], so that students can analyze and use this kind of circuit system when they encounter it in life, etc. Although the theoretical research is abundant, experimental practice is neglected.

One group also focuses on the practical inquiry. For example, teacher Yiyong Xu used the acoustic and optical control module circuit, and asked students to connect them with wires and debug modules [5]; Teacher Zhibin Qiang made students experience the fun of circuit welding through the process of making a “breathing lamp” [6]; Using bread board and some common electronic components such as resistors, diodes and transistors, Teacher Kui Cao designed and developed a set of interesting electronic demonstrators that can be assembled quickly by students [7], etc. Although these create real situations for students, most of the content is a verification experiment, and students are easy to walk in the wrong way for the purpose of verification results. In addition, a 5 V DC power supply is used in existing demonstration experiments, which is expensive and difficult to obtain. For battery-powered demonstrators, the input state cannot be switched at will, the power supply and the ground need to be switched by welding with wire each time, which is not flexible enough and the operation is tedious, increasing the potential safety hazards, etc.

In view of these problems, I adopted quantitative means for the selection of components, layout, wiring, as well as the design of logical implementation effect, etc. To produce a more standard, safe and reliable gate circuit teaching instrument, the experimental phenomenon is intuitive with good operability and repeatability.

The structure of this paper is arranged as follows: The second part is the analysis of the teaching materials and the students’ learning situation. The third part sets out the teaching goals and difficulties of the course “Senior High School Physics Logic Circuit”, the teaching process includes the introduction of new lessons, the explanation of new lessons, and detailed analysis and explanation of the self-made physical teaching instrument. The fourth part is the ideological and political part of the course, to carry out scientific literacy and patriotism education for students. The fifth part summarizes the advantages of this teaching instrument and sets goals for further research.

2. Analysis of Teaching

Logic circuit is involved in various versions of senior high school physics, such as Cantonese version, JKWL, SHKJ (trial edition) and other textbooks, although the syllabus is less demanding for this lecture [8], modern information technology characterized by digital signal is developing rapidly, logic circuit is arranged on the basis of the students’ systematic learning of circuit, electronic components, the use of multi-purpose electricity meters and other knowledge, to prepare for the teaching of sensor knowledge, but also the preliminary knowledge of the entry-level theory of modern electronic technology, which is in line with students’ cognitive development and has popular science nature.

Experiment plays an important and irreplaceable role in physics teaching.

Through experiment, students can have “Objects” and “Reason” in their minds. When teachers do experiments with self-made teaching instruments, they can make students deeply feel the existence of physical knowledge in life, and gradually develop the awareness and habit of taking the initiative to use objects around them to conduct scientific inquiry, which is conducive to cultivating students’ intelligence and creativity.

This class is for the second grade students of senior high school, and they are active in thinking and have certain knowledge accumulation and independent thinking ability, also curious about new things and interested in advanced science and technology. Before the knowledge of logic circuit, the textbook “Electrical Part” has systematically introduced the knowledge of electric potential difference from the electric field aspect, under the action of static power, the positive and negative charges move in the high and low potential position, common circuit components and their functions in the circuit, etc. Students are accustomed to understanding and analyzing simple functional relationships (e.g. proportional, inverse, etc.) that change continuously in analog circuits, preferring theoretical analysis circuits [9]. In the existing teaching design, the teacher often adopts the concept teaching method, after introducing the three circuits, they are eager to explain and analyze the control circuit examples, and lack of corresponding physical experiment teaching instruments, therefore, the experimental demonstration was turned into a teacher’s “Speaking Experiment”. Since it is the first time for students to touch the logic circuit, this will make students confused.

3. Teaching Design

3.1. Teaching Goals

- 1) Know two types of electrical signals: Analog and Digital.
- 2) Master three kinds of gate circuits: Logical functions of “AND” gate, “OR” gate and “NOT” gate, logic truth table and logic function expression.
- 3) Learn to analyze simple practical applications of logic circuits, and be able to design and build logic circuits according to the requirements.
- 4) Through the experiment to cultivate students’ ability of observation, analysis, reasoning, summary ability and problem-solving ability.

3.2. Key Points and Difficulties

- 1) Logic functions of the three simple gate circuits.
- 2) The design and working principle analysis of gate circuit composed of diode.
- 3) Understanding of the layout of the components and the routing on the PCB board.

3.3. Teaching Process

3.3.1. Importing New Lesson

In modern society, digital electronic products have been inseparable from our

daily life, such as mobile phones, computers, etc. The circuit that processes digital signals is called digital circuit. There are two kinds of electrical signals, one is analog: Voltage signals that change continuously, such as audio signals; the other is digital signal: There are only high voltage and low voltage states. It is generally stipulated that high voltage is represented by the Arabic numerals “1”, and low voltage is represented by “0”, which forms a digital signal composed of “1” and “0” [10]. Guide students to observe the waveform chart of digital signal (as shown in **Figure 1**) [11], analyze and summarize the value of digital signal is discrete in time and has the characteristics of jump.

Digital circuit mainly realizes the logical relationship between input and output signals, so digital circuit is also called logic circuit. What is logic? At this time, students diverge their thinking and express their understanding of logic from the perspective of literature and mathematics. In the discussion of students, I summed up the general understanding of logic: The relationship between “Condition” and “Result”. For example, during the epidemic prevention and control period, students can only enter the school by showing their health code, then showing their health code is the condition, while allowing students to enter school is the result. Log in QQ, you must enter the correct user name and password to be able to log in successfully, input these account information is the condition, allow login is the result, these conform to the reality of life and are easily accepted by students. Therefore, the “logic circuit” is that the condition is satisfied, the signal is allowed to pass through the circuit, the condition is not satisfied, the signal is blocked outside the door. “Gate” circuit is a kind of condition switch, analysis and study of the logic of “gate” circuit, but also to understand the digital signal processing, is in essence to deal with a logical relationship. Next, learn the three simple logic gates.

3.3.2. New Course Teaching

1) “AND” Gate

Ask the students to analyze the logical relationship between the two switches and the bulb L according to the knowledge of series circuit (as shown in **Figure 2**) [12]. After discussion, it is easy for students to draw the conclusion that only when A and B are turned off at the same time, the bulb L will be lit. In this event, the condition is that “switch A is on” while “switch B is on”, resulting in “bulb L is on”. Like this: If several conditions of an event are met, the event can happen,

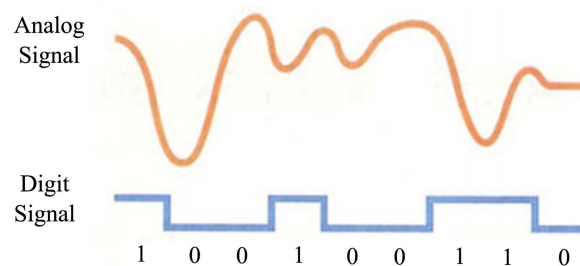


Figure 1. Analog and digital signals.

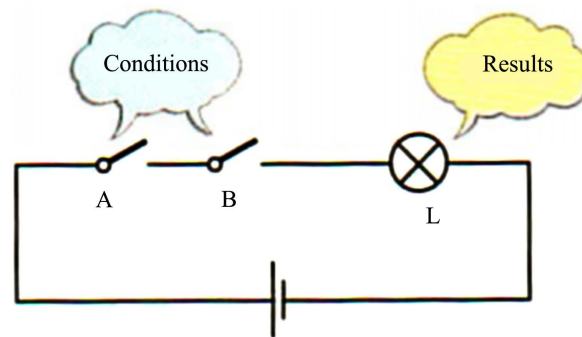


Figure 2. “AND” logic circuit.

We call this relationship “AND” logical relationship, the circuit which has the logical relation of “AND” is called “AND” gate circuit, and “AND” gate for short.

A switch has two conditions, on and off, then the combination of the two switches in the picture has four conditions, we list all the conditions of the switch and the possible lighting of the bulb (as shown in **Table 1**). We can also use the mathematical language to define the switch on as 1, off as 0, bulb on as 1, extinguish as 0, Forming a table representing various control conditions and control results with numbers, we call this table representing all possible states between the input and output of logical events a truth table (as shown in **Table 2**). Teachers should emphasize that the numbers “0” and “1” here represent two logical states, rather than quantitative concepts.

The common power switch in life is also printed with the numbers 1 and 0, as shown in **Figure 3**. Note that “1” represents switch on and “0” represents switch off, not the abbreviation of IN and OUTPUT!

In the circuit, the “AND” gate is represented by a box and a “&” symbol, as shown in **Figure 4** [12], A and B are the input and Y is the output. “&” is synonymous with the English word “AND”. According to the truth table, it can be concluded that only when input terminal A and terminal B are both 1 can the output terminal be 1, as long as there’s a 0 on the input, the output is 0. Then the mathematical logic expression of “AND” is established between the output and input: $Y = A \cdot B$.

2) “OR” Gate

Let’s change switches A and B in **Figure 2** into parallel connections, as shown in **Figure 5** [12], to make the bulb light, no matter how many switches are connected, do you only need to select one to turned off? It goes something like this: If only one of several conditions is met, something will be happen, this relationship is called “OR” logic. A circuit with the “OR” logical relationship is called “OR” gate. It is also possible to list the state table and truth table of the “OR” logic circuit (which can be listed by students).

The “ ≥ 1 ” in the symbol of “OR” gate indicates that: When one or more inputs are 1, the output is 1, and the output is 0 only if all the inputs are 0, as shown in **Figure 6** [12].



The common power switch in life is also printed with the numbers 1, 0, “1” represents the switch on, “0” represents the switch off.

Figure 3. Common power switch.

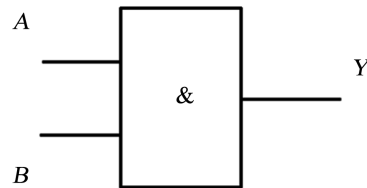


Figure 4. “AND” gate symbol.

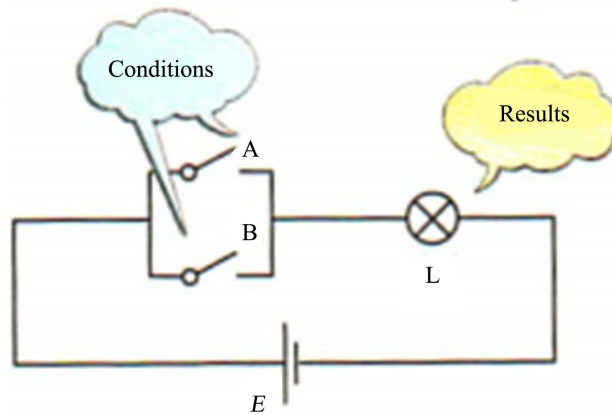


Figure 5. “OR” logic circuit.

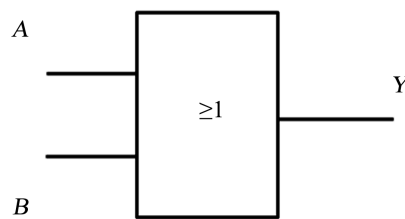


Figure 6. “OR” gate symbol.

Table 1. “AND” logic circuit status table.

Conditions		Results
A	B	L
off	on	Put out
on	off	Put out
on	on	light up

Table 2. “AND” logic circuit truth table.

Conditions		Results
A	B	Y
0	1	0
1	0	0
1	1	1

3) “NOT” Gate

What is the logical relation of “NOT” gate circuit? “NOT” literally means negative, so in a circuit does it mean that the output state is opposite to the input state? Let’s look at the “NOT” logical circuit in **Figure 7** [12]: “switch on, bulb off”, “switch off, bulb on”, such a logic circuit whose output state and input state are opposite is called “NOT” logic relation, and the circuit with “NOT” logic relationship is called “NOT” gate, the logical symbol of “NOT” gate is shown in **Figure 8** [12].

3.3.3. Make a “AND” Gate Physical Circuit

We previously used the two states of the mechanical switch on and off, and the students are familiar with the DC circuit to simulate various logical relationships. In addition to mechanical switches, what component we learned has two states? Ask questions that remind students of what they learned about diodes, so can we use the unidirectional conductivity of diode (as shown in **Figure 9**) [13] to realize the gate circuit with logical function? Here is a “AND” gate demonstration aid built by diodes.

As shown in **Figure 10**, the positive voltage is high potential to the common reference point GND, which is called high level in the logic circuit, and the negative GND is low potential, which is called low level. There is a LED at the right indicating the high or low level of the output, and the output voltage can also be measured with a voltmeter.

The current is going in this direction: For example, if A-end is connected to 0, the left end of D1 is also connected to low level, and the right end of D1 is connected to the power supply through the resistance, then the right end of D1 is high level, Diode D1 was conducted, which is equivalent to a wire. The current which flows from the power supply V_{cc} to resistor R1, diode D1, A, and GND to form a current loop. The voltage between Y and GND is also the positive guide voltage of the diode D1, this voltage is too small to make the LED light up, indicating the Y-end’s output is low level; Similarly, either A or B is connected to 0 can make the diode conduction, the output voltage of Y-end is almost 0, so the LED don’t light up; If A and B are all connected to the high level, the left of the circuit is have no potential difference, both diodes cut off, the voltage at the Y-end is the same as the voltage at the upper end of the resistor, then the output is high level, the LED obtains the working voltage and lights up, so that

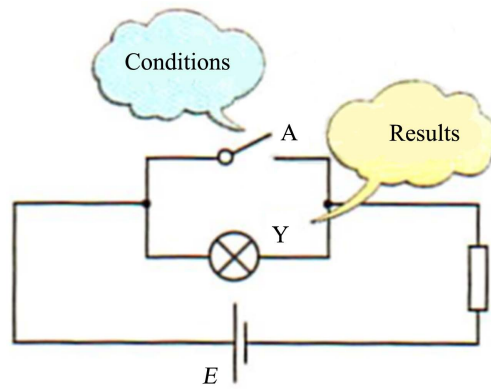


Figure 7. "NOT" logic circuit.

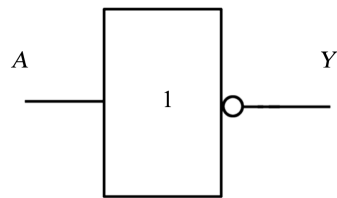


Figure 8. "NOT" gate symbol.

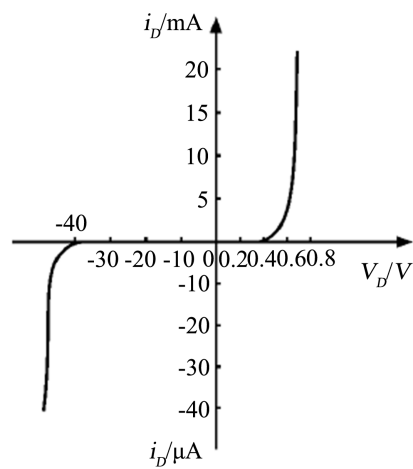


Figure 9. Conductive characteristics of diode.

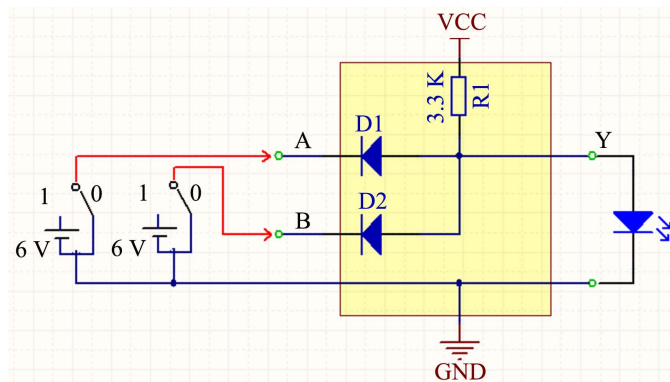


Figure 10. Schematic diagram.

a resistor and two diodes constitute a simple demonstration of “AND” gate circuit.

After the analyzing of the circuit, what equipment do we need to make a physical teaching aid?

Bill of materials and material parameters:

Component Name	Number	Parameter	Remark
Universal PCB board	1	Double-sided and single-hole plate	/
Battery Holder	1	No. 5, no cover and no switch	/
Battery	4	No.5 (1.5 V/PCS)	Four batteries are connected in series to provide 6 V DC power
Twist Switch	2	Single row, 3 pin 2 gear	The middle end is the input terminal, and the two ends are the output terminal
Switching Diode	2	1N4148, General application, high switching speed, low current, $V_R: 75\text{ V (max)}$, $I_F: 150\text{ mA}$, $V_F: 0.62\text{ V (}I_F = 5\text{ mA)}$	Low price and easy to obtain
Resistance	1	3.3 K, 1/4 W color ring resistance	/
LED	1	Straight plug $\Phi 5$, $V_F: 2 - 2.2\text{ V}$, $I_F: 20\text{ mA}$	The normal working current is small, low price and easy to obtain
Wire	/	28 AWG, red, black	/

Universal board is an experimental board which is commonly used for students to do electronic design. This time, it is a single-hole board, which is more suitable for digital circuits and the connected lines are more regular. The board can be bought in Taobao or electronic market. It should be noted that the size of the universal board should be reasonably selected according to the size of the circuit, so as to save materials. Batteries can be bought from the store or disassembled from the children’s electric toys. The input of the gate circuit and the twist switch are matched to select high or low levels for A and B. In the process of production, we should note that the middle foot of this 3-foot single row switch is generally the common terminal, when the twist is hit to the left, the middle claw is connected to the right, the twist is hit to the right, the middle claw is connected to the left. Not the other way around!

The common power of the color ring resistance is 1/4 W, 0.5 W, 1 W, 2 W, etc. So what kind of power resistance should be chosen? According to the data manual, the normal working voltage of the led is 2 - 2.2 V, then the partial voltage on the 3.3 K resistor is 4 - 3.8 V, according to the power calculation formula: $P = U^2/R$, the result is about 0.0044 W - 0.0048 W, so the resistance of 1/4W is fully satisfied with the use. The main components used are shown in **Figure 11**.

Insert all kinds of components on the universal board, and fix it around with screws. The teaching instruments are small and beautiful, as well as convenient to show to students. For tidiness, the actual wiring is distributed on the back. **Figure 12** is the PCB wiring diagram which was drawn with Altium Designer 09 software. Altium Designer is an integrated electronics development system from the software developer Altium, which is mainly used for schematic diagram and printed circuit board design. The drawing of **Figure 12** can be directly sent to PCB manufacturer for production. Students can compare and explore the wiring of PCB drawings with the schematic diagrams or the physical teaching instruments independently, you can also build a reasonable circuit by yourself according to the wiring diagram and device layout, so as to have a deeper understanding of the embodiment of the current loop in physics in the actual circuit wiring, and build a bridge of knowledge between the circuits learned in middle school and electricians and electronics in higher education in students' minds. At the same time, it gives us inspiration: The materials should be as easy as possible to obtain, so that students can repeat and improve the experimental production after class.

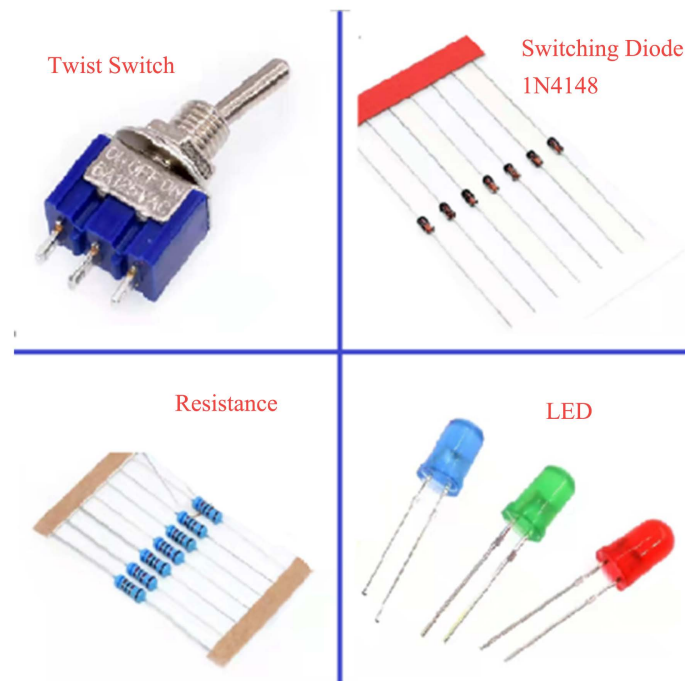


Figure 11. Main components.

In the process of teaching, teachers must explain clearly to students that “1” and “0” cannot be defined according to the on or off of the switch in the logic circuit, but should be defined according to the input signal of the logic gate, that is, the input signal is defined as “1” when it is high voltage, and the input signal is defined as “0” when it is low voltage [14]. When conceiving the teaching instruments, hit the twister switch to the position marked “1” on the screen of the board so that it is just switched on high level, and the position of “0” is just switched on low level. Reduce unnecessary misunderstanding to students. As shown in **Figure 13**, dial the two twist switches to the upper part and select 1, that is, the A and B terminals are connected with high level, the two diodes are cut off, and the power supply, resistor and LED form a current loop, the LED lights up.

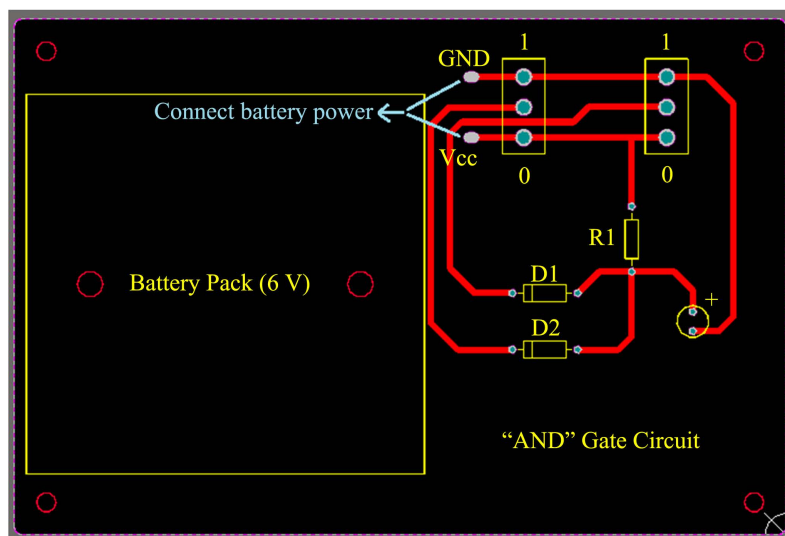


Figure 12. Actual routing diagram (Drawn by Altium Designer 09).

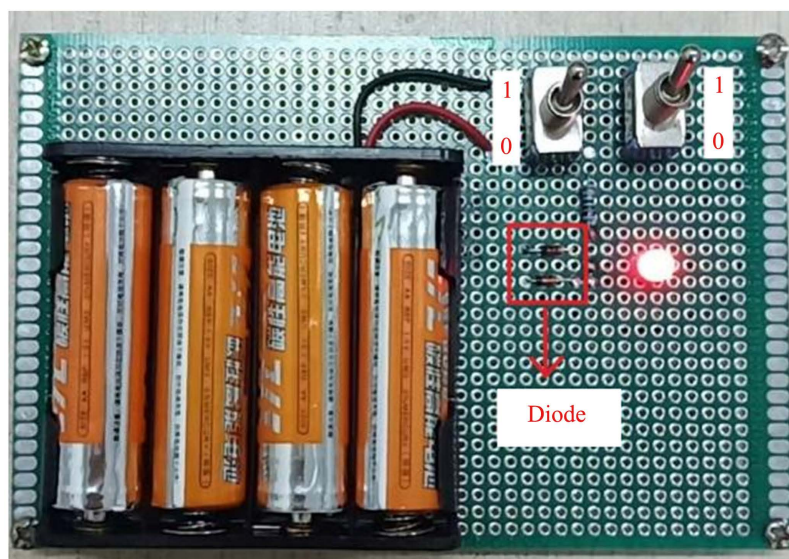


Figure 13. Picture of the teaching instruments.

Once the “AND” circuit was understood, the teacher can set questions after class and give students tips: Combined with the characteristics of “OR” gate circuit, try to build a “OR” gate circuit by diode, guide students to change their thinking, analyze and solve problems in different ways, deepen the understanding of this section of knowledge points, promote the development of scientific thinking of students. When designing a circuit, there are certain steps to follow. Such as parameter calculation, device selection and layout, wiring, etc. Students can refer to the “AND” gate object to make “OR” gate circuit, or let students from their understanding of the logical relationship design circuit to verify, deepen the understanding of the circuit, improve their logical reasoning ability and experimental operation ability.

4. Curriculum Ideology and Politics

In practical application, logic gate is an integrated circuit that concentrates various components on a silicon wafer, and it is a device that processes the logic state of input and obtains specific output state. Teachers should guide students to understand that this is a method of black box thinking, and don't care about the internal specific circuit, this thought guides us to ignore the irrelevant appearance in the analysis of the problem, ignore the local irrelevant complex system and grasp the essence of the problem from the whole [15]. To do this: A simple logical element can be applied to an appropriate control circuit according to the logical relationship described in its data manual. “Take it and know how to use it” is also a necessary skill for modern people.

We packaged the two diodes and the resistor of the “AND” gate circuit, with the interface reserved, and made it into module, thus making a low-configuration version of the “Integrated-AND Gate” circuit. The current trade war between China and the United States, where the United States controls the export of cutting-edge technologies such as high-end chip technology, has brought many difficulties to Chinese development. Let the students know that the logic circuit knowledge we have learned is the basis of IC chip technology, so our learning is very meaningful. Teaching is permeated with a scientific attitude to stimulate students' patriotic enthusiasm and interest and motivation to study physics.

5. Conclusions

This teaching design is an exploration of the teaching method that combines education and teaching with science and technology, and integrates science and technology into the experiment of senior high school physics class teaching effectively. Based on the circuit in the “Demonstration” column of the PEP edition textbook and according to the cognitive development level of students, I made a “AND” gate experimental teaching instrument that can select input state flexibly and display output state stably. Due to the independent design and production, this teaching instrument is more flexible than a factory teaching instrument, and the teaching material is more adaptable, low cost, economical and practical, and

easy to promote. At the same time, it is also a supplement and improvement of the current teaching instrument of physics experiments. Through theoretical learning and practical operation to expand students' horizons and knowledge depth, let students break through the shackles of thinking, and help students to learn and master the knowledge of high school physics.

In the next step, I will continue to refer to the improvement of the relevant experimental circuits in textbooks by experts, and triodes will be used in experimental research on gate circuits, and simulation demonstration will be made in combine with electrical simulation software such as Multisim, so as to explore higher-level research-based courses.

Conflicts of Interest

The authors declare no conflicts of interest.

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