Hong Kong Student Science Project Competition 2023

Extended Abstract (Investigation)

(Word Limit: 1,600 words, Pages: 3 pages only)

Team Number: SBBC066

Project Title: Investigating the effect of different transition metal cocatalysts on yield of hydrogen evolution in photocatalytic water splitting.

Project Type: Investigation

***To our best knowledge, there are / are no * similar works in the field*; (if there are,) related research links are as below:**

https://www.researchgate.net/publication/323016940_Synthesis_and_Characterization_of_Ni_Doped_TiO2_Nanoparticles_by_Sol-Gel_Method

The enhancement our project made / the difference with related research are:

The transition metal used as a cocatalyst was varied rather than concentration or precious metal cocatalysts.

Please delete if not applicable. The competition values the originality of works. Students must do enough literature research to ensure that their works are unique and list relevant reference materials before starting research or invention.

I. Background

The energy production industry contributes to 25% of global greenhouse gas emissions (United States Environmental Protection Agency), contributing to the pressing issue of climate change. Therefore, converting to cleaner energy production methods is more important than ever. Hydrogen can be isolated from water and used in hydrogen fuel cells, which is a "clean fuel" as it "produces only water" upon consumption (Office of Energy Efficiency & Renewable Energy). Water can be split in multiple ways, including thermolysis, biological means and photocatalysis. Photocatalysis, the splitting of water through the interaction between light and the photocatalyst, provides low cost and minimal environmental impact while maintaining chemical and physical stability (Deng et al.) Precious metals such as platinum, silver and gold act as cocatalysts, improving the efficiency of photocatalysts (Jeon et al.). However, they are also costly, leading to the need for lower-cost alternatives.

II. Objectives

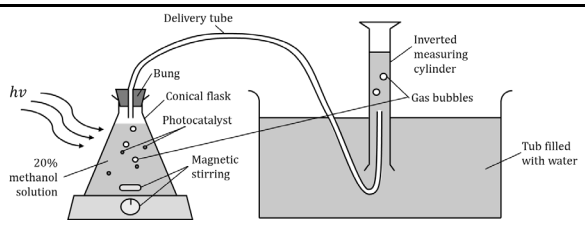
This paper aims to determine a relationship between the properties of transition metal cocatalysts and their effectiveness in catalysing water splitting. From here, an optimal, affordable alternative to precious metal cocatalysts will be determined.

III. Hypothesis

The excitation of TiO2 by light produces electrons and holes, which reduces H^+ ions and oxidises H_2O to form hydrogen and oxygen gas respectively (Eidsvag et al.). Metal dopants on TiO2 can enhance its catalytic activity by increasing light absorption (Jeon et al.), encouraging separation of electron-hole pairs (Meng et al.), and improving reactant adsorption (Meng et al.). In particular, the work function of the metal cocatalyst affects the ability of the cocatalyst to trap charge carriers (Meng et al.). We predict that the higher the work function of the metal cocatalyst, the more the amount of H_2 evolved. We can test this hypothesis through synthesising transition metal doped TiO2, and measuring the amount of H_2 evolved after leaving the catalyst in water for a period of time.

IV. Methodology

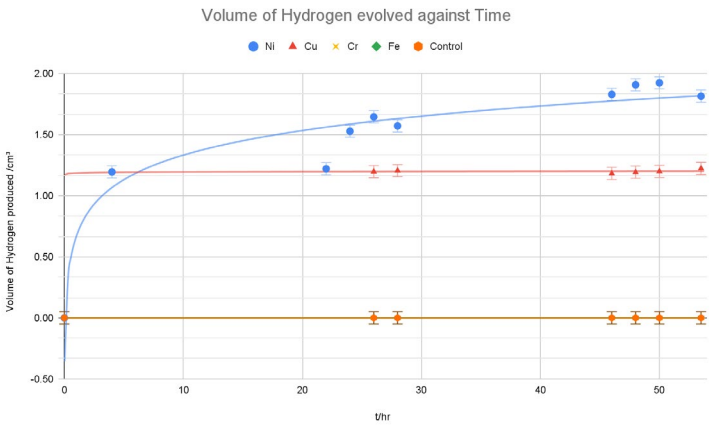
In this investigation, the efficiency of nickel, copper, chromium and iron doped photocatalysts were investigated. The sol-gel method was adopted for synthesising the catalysts. 16cm^3 of 1% transition metal nitrate solution (pure water for control) was dissolved in 4.0cm^3 of chelating agent (ethanoic acid) and 6.0cm^3 of solvent (ethanol) (Senain et al.) alongside 7.5cm^3 of titanium butoxide. This mixture was then placed in an electric oven at 60.0°C overnight to evaporate excess water and ethanol. Lastly, the gel was collected from the oven and was calcined at 500.0°C for 8 hours, forming transition metal doped TiO_2 crystals.



0.050g of photocatalyst was placed in a 100.0cm^3 conical flask with 20% methanol solution acting as a sacrificial electron donor (Schneider and Bahnemann). An inverted measuring cylinder (±0.05cm^3) setup was used to measure the volume of gas produced. A lamp of 100W was used as a source of light for the photocatalytic reaction. The mixture in the conical flask was placed under magnetic stirring for 54 hours.

V. Results

	Volume of Hydrogen produced (V/cm³)				
Time (t/hr)	Ni	Cu	Cr	Fe	Control
0	0.00	0.00	0.00	0.00	0.00
4	1.20	N/A			
22	1.22				
24	1.53				
26	1.65	1.20	0.00	0.00	0.00
28	1.57	1.21	0.00	0.00	0.00
46	1.83	1.18	0.00	0.00	0.00
48	1.91	1.19	0.00	0.00	0.00
50	1.92	1.20	0.00	0.00	0.00
53.5	1.82	1.22	0.00	0.00	0.00



Through the graph, it can be observed that without a metal cocatalyst, minimal and unquantifiable amounts of hydrogen gas is evolved. Nickel cocatalysts provide the largest yield of hydrogen gas of 1.93cm^3, followed by copper cocatalysts at 1.22cm^3. This can be implied through observing the gradient of the trend line; a greater instantaneous gradient signifies a rapid rate of reaction. Both chromium and iron cocatalysts give unquantifiable results. Hence, it can be concluded that nickel cocatalysts are most effective. The results may be limited in terms of frequency of data- to accommodate the school schedule, data could not be collected at some times. Additionally, the scale of the experiment was smaller than other works, leading to larger uncertainty. This investigation allows for a greater efficiency of generating energy, while allowing for lower operating costs, meaning that it can be used in developing countries.

VI. If your team will compete the Sustainable Development Award, please indicate the specific sustainable development goal the project is related to, and provide justification for competing for this award. *(Word limit: 300 words)*

As established earlier, the hydrogen obtained from this setup can be used in hydrogen fuel cells to generate power, providing a clean alternative to combusting fossil fuels. Therefore, this investigation contributes to goal 7 of the United Nations Sustainable Development Goals, "Affordable and Clean Energy". Geographical factors for certain clean energy sources are now alleviated. For example, hydroelectric power or wind turbines, which require proximity to a river and open space respectively, and may not be accessible in various locations around the world. On the contrary, sunlight is abundant across the globe and does not require specific terrain advantages to utilise for power generation, thereby increasing the feasibility of its implementation in inland or landlocked areas far from water basins. This makes photocatalytic water splitting an attractive source of hydrogen gas. Furthermore, due to the affordability of transition metals such as nickel and copper in addition to low operating costs, doped photocatalysis of water can be a cheaper alternative to photovoltaic cells, which are estimated to cost 396USD/MWh (Koerth-Baker). This will make clean energy more widely available, especially in developing countries that may not have the resources to invest in renewable energy infrastructure. Tackling goal 7 is step one of a gradual process to reach the UN's vision for a sustainable future. Once clean energy is affordable and widely available, people can strive to construct sustainable cities and communities, goal 11. When these sustainable cities and communities become more widespread, climate action, goal 13, among other environmental issues can be addressed as a global unity. Therefore, when considering the bigger picture, this study is only a small step towards a larger goal. However, it is the accumulation of these small steps that allow society to progress and conquer new heights.

VII. If your team will compete the Social Innovation Award, please list the target group or social issue the project focuses on, and provide justification for competing for this award. *(Word limit: 300 words)*

N/A

VIII. Conclusion

The results of this investigation concludes that nickel and copper doped TiO_2 photocatalysts yield the most hydrogen gas. This result agrees with our initial hypothesis, as both nickel and copper have a relatively higher work function compared to iron and chromium. For further investigation, we propose research into the impacts of work function on the efficiency of the cocatalyst. To do this, the experiment can include a wider range of transition metals. Furthermore, we suggest characterising the doped catalysts in order to gain more insight into its properties and make better predictions. Last but not least we could investigate the impacts of different preparation methods on the efficiency of the cocatalyst. By gaining further insight into the function of cocatalysts in the photocatalytic water splitting reaction, we would be able to contribute to the social developmental goal of "Affordable and Clean Energy".

× Our project is developed based on previous project and the enhancement is below:

N/A