WACE 2015 Q38:

Two different coloured cobalt(II) complex ions, $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$, exist together in equilibrium in solution in the presence of chloride ions. This is represented by the equation below.

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4\,Cl^-(aq) \rightleftharpoons \underset{\text{blue}}{CoCl_4^{2-}(aq)} + 6\,H_2O(\ell)$$

An experiment is conducted to investigate the effects on the equilibrium position by imposing a series of changes on the system. The shift in equilibrium position can be indicated by any colour change of the system.

Colour chart	
Species	**Colour**
$Co(H_2O)_6^{2+}(aq)$	pink
$CoCl_4^{2-}(aq)$	blue
Initial equilibrium mixture	purple

After a 3.00 mL sample of an initial equilibrium mixture was placed in each of three test tubes, changes to each system were made by adding a different substance, as indicated in the table below.

Test tube	**Substance added to the test tube**
1	10 to 12 drops of distilled water
2	20 to 25 drops of concentrated hydrochloric acid
3	20 to 25 drops of 0.200 mol L^{-1} silver nitrate solution, $AgNO_3(aq)$

(a) Complete the table below by predicting the:

- change in concentration, if any, of each of the ions in solution compared to the initial solution, after a new equilibrium position is reached
- colour change, if any, that takes place from the initial purple-coloured solution

Additions to the test tube	**Change in concentration from initial equilibrium to final equilibrium (increase, decrease, unchanged)**			**Colour favoured (pink, blue or unchanged)**
	$[Co(H_2O)_6^{2+}]$	**$[Cl^-]$**	**$[CoCl_4^{2-}]$**	
1. add $H_2O(\ell)$				
2. add $HCl(aq)$				
3. add $AgNO_3(aq)$				

(b) Other than a colour change, what else should be observed in test tube 3? (1 mark)

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(c) Using Collision theory, explain your predicted observations when hydrochloric acid is added to test tube 2. (3 mark)

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Another experiment was conducted to investigate the effect that changing the temperature had on the equilibrium mixture. When 3.00 mL of the original equilibrium mixture was placed in a test tube and then in an ice bath, the solution became pink.

(d) Determine whether the forward reaction, as illustrated by the equation below, is exothermic or endothermic. Use Le Châtelier's Principle to justify your answer.

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4\ Cl^-(aq) \rightleftharpoons \underset{\text{blue}}{CoCl_4^{2-}(aq)} + 6\ H_2O(l)$$

(4 marks)

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(e) State **one** specific hazard to the environment that the disposal of chemical from this experiment poses and state what could be done in the laboratory to reduce this hazard. (2 marks)

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WACE 2013 Q29:

Write the equation and the expression for the equilibrium constant for each of the equilibrium processes below. (4 marks)

Equilibrium process	Equation	Equilibrium constant expression
Vaporisation of water		
Dissolution of solid aluminium sulfate in water		

WACE 2012 Q42:

Large public swimming pools are often chlorinated using chlorine gas. The gas is bubbled through the water forming the equilibrium reaction shown below:

$$C\ell_2(aq) + H_2O(\ell) \rightleftharpoons HOC\ell(aq) + H^+(aq) + C\ell^-(aq) \qquad \text{(Reaction 1)}$$

The equilibrium constant for this reaction at 25.0 °C is 3.94×10^4.

(a) Compare the relative amounts of chlorine and hypochlorous acid ($HOC\ell$) at equilibrium at 25 °C. (1 mark)

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The hypochlorous acid can dissociate as shown in the equilibrium below to give hypochlorite ion.

$$HOC\ell(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OC\ell^-(aq) \qquad \text{(Reaction 2)}$$

(b) The pH of swimming pools is kept at approximately 7.5. A reason for this is to maximize the concentration of hypochlorous acid, the most effective disinfectant form of chlorine in water. Explain, using the appropriate chemistry concepts, why a pH of about 7.5 will maximize hypochlorous acid concentration. Your answer should consider equilibrium Reactions 1 and 2. (3 marks)

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WACE 2012 Q29:

The white solid bismuth oxychloride reacts with concentrated hydrochloric acid to establish the following equilibrium:

$$BiOC\ell(s) + 2\,H^+(aq) \rightleftharpoons Bi^{3+}(aq) + C\ell^-(aq) + H_2O(\ell)$$

Three test tubes of the equilibrium system, 'A', 'B' and 'C' were prepared by adding excess $BiOC\ell$ to concentrated hydrochloric acid.

Complete the table below by indicating the direction of the expected shift in equilibrium immediately following the changes stated in the table. Give the reason for shift. (6 marks)

Test tube	**Change**	**Direction of shift in equilibrium ('left', 'right' or 'no change')**	**Reason for shift**
A	3 mL of water is added		
B	A few drops of concentrated nitric acid are added		
C	A few drops of concentrated silver nitrate solution are added		

WACE 2010 Q26:

Consider the following system:

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -92\ kJ$$

(a) Predict whether the following changes will increase, decrease or have no effect on the rate of attainment of equilibrium. (3 marks)

Change	Effect
Decreasing the temperature	
Increasing the pressure of hydrogen	
Adding a catalyst	

(b) Predict whether the following changes will increase, decrease or have no effect on the equilibrium yield of the reaction. (3 marks)

Change	Effect
Increasing the temperature	
Increasing the pressure of the system	
Adding a catalyst	

WACE 2010 Q27:

Write the equilibrium constant expression for the following equilibria:

(a) (1 mark)

Equation	$BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$
Equilibrium constant expression	

(b) (1 mark)

Equation	$2\,CrO_4^{2-}(aq) + 2\,H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(\ell)$
Equilibrium constant expression	

TEE 2009 SA Q5:

Solid magnesium hydroxide is added to a beaker of water. The water is stirred and the contents of the beaker left to settle. A saturated solution is formed, with undissolved magnesium hydroxide at the bottom of the beaker. The system can be shown by the following equation:

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2\ OH^-(aq)$$

(a) The system is allowed to come to equilibrium. Explain why the amount of solid present remains constant. (1 mark)

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(b) The changes indicated in the table below are now imposed onto the system. Predict and explain the effect these changes have on the amount of solid magnesium hydroxide in the beaker once equilibrium is re-established. (6 marks)

Imposed change	**Effect on solid $Mg(OH)_2$ (write 'increase', 'decrease' or 'no change')**	**Explanation**
A little concentrated sodium hydroxide solution is added		
Some sodium phosphate solution is added to the beaker		
More water is added to the beaker		

WACE 2010 Q28:

Ammonia is able to react with itself in the process known as 'self-ionisation'. The equation for the self-ionisation of ammonia is below.

$$NH_3(aq) + NH_3(aq) \rightleftharpoons NH_4^+(aq) + NH_2^-(aq)$$

(b) At standard temperature and pressure, the equilibrium constant, K, for this reaction is about 1×10^{-30}. The self-ionisation of ammonia is an endothermic process. Will the value of K be less than or greater than 1×10^{-30} at temperatures greater than 0 °C? Explain. (3 marks)

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TEE 2007 SA Q6:

An equilibrium is set up in a test tube by suspending some finely powdered copper sulfide in a dilute solution of hydrochloric acid. The equation for the equilibrium is:

$$CuS(s) + H^+(aq) \rightleftharpoons Cu^{2+}(aq) + HS^-(aq)$$

For each change, list:

- the **immediate** effect on the rate of the forward reaction
- the effect on the yield of HS^- **after equilibrium has been re-established**

Answers should be given as 'increase', 'decrease' or 'no change'. (6 marks)

Change made to the equilibrium system	**Immediate effect on rate of forward reaction**	**Effect on equilibrium yield of $HS^-(aq)$**
$HC\ell(g)$ is passed into the solution		
$CuSO_4$ solution is added		
More of the finely powdered CuS is added		

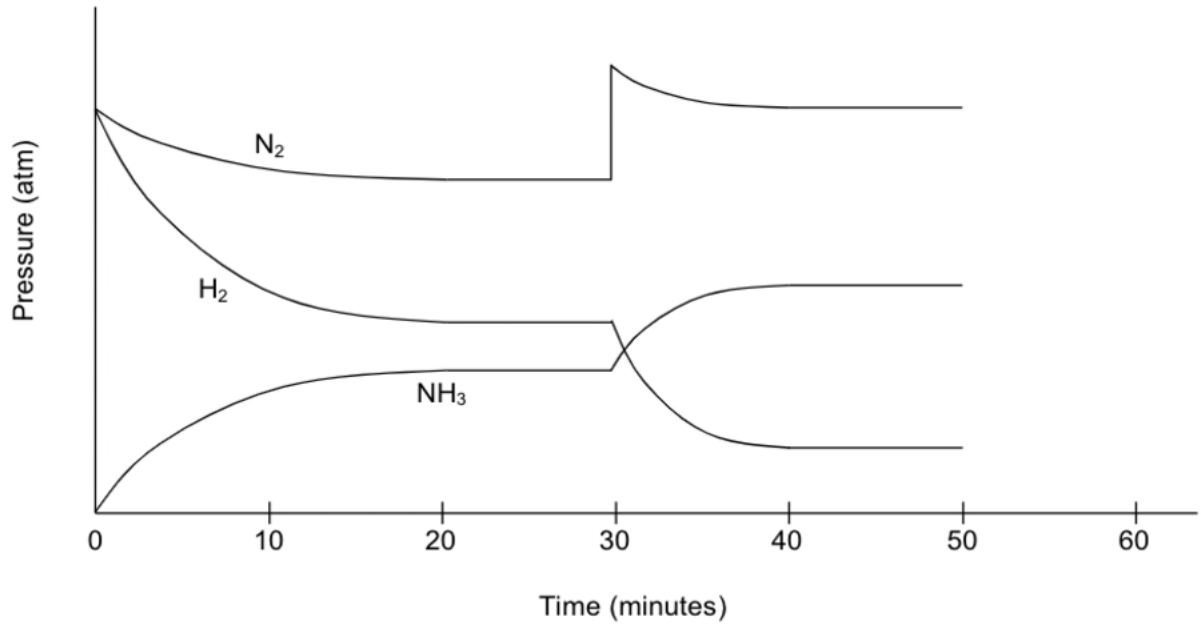
TEE 2007 SA Q5:

Ammonia is an industrially important gas produced by the Haber process, as illustrated by the reaction below:

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g) \qquad \Delta H = -92\ kJ\ mol^{-1} \quad (at\ 25\ °C)$$

The reaction is catalysed by iron(III) oxide, Fe_2O_3.

The following graph shows the partial pressures of the three species involved in the reaction.



Answer the following questions about the above graph.

(a) Why does the partial pressure of the H_2 decrease more rapidly than that of the N_2? (1 mark)

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(b) Why do the partial pressures of each of the three species stabilise between 20 and 30 minutes? (1 mark)

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(c) What has occurred at the 30-minute mark to cause the changes shown in the graph? (1 mark)

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(d) By the 40-minute mark, what difference will the change imposed at the 30-minute mark have made to the rate of: (2 marks)

the forward reaction? .....

the reverse reaction? .....

(e) Using the Collision Theory, explain why the rate of forward reaction is affected by the imposed change at the 30-minute mark. (2 marks)

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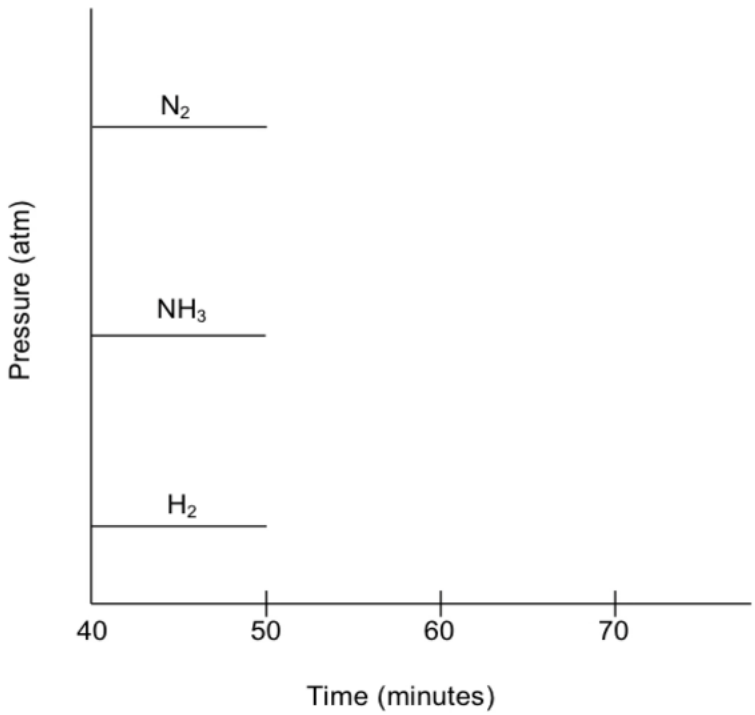
(f) At 50 minutes, the contents of the reaction vessel are rapidly compressed by reducing the volume. The changes in the partial pressures of the species are shown on the following graph, starting at 40 minutes.



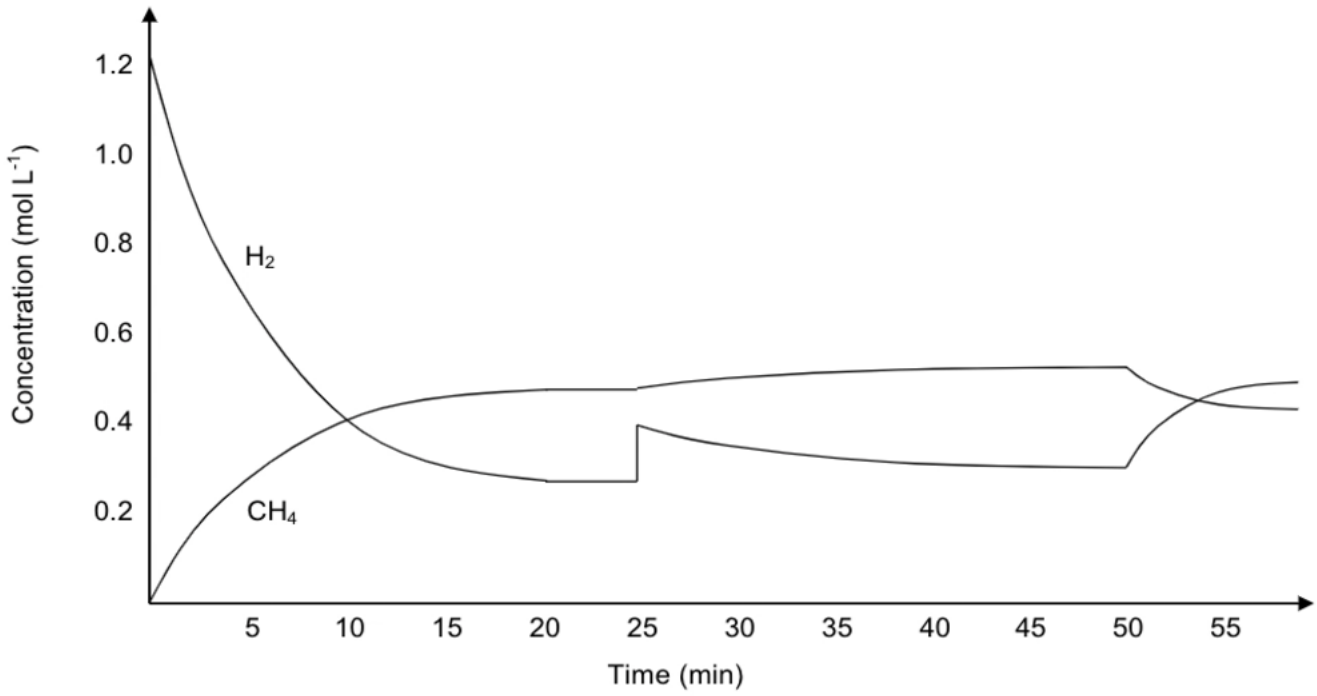
Complete the above graph up to 70 minutes by shown how the partial pressures of each of the species change as a new equilibrium is achieved. (3 marks)

TEE 2005 SA Q7:

The reaction between carbon and hydrogen gas to form methane can be represented by the following equation.

$$C(s) + 2\,H_2(g) \rightleftharpoons CH_4(g) + 75\ kJ$$

The concentrations of hydrogen and methane were plotted over time and the following graph produced.



(a) What time was equilibrium first established? (1 mark)

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(b) Suggest what could have caused the change at the 25 minute mark. (1 mark)

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(c) Suggest what change to the system occurred at the 50 minute mark. (1 mark)

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(d) What would be the effect on the equilibrium if more C(s) was added to the system? (1 mark)

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(e) Predict, using Le Châtelier's Principle, what would be the effect of halving the volume of the reaction container. (2 marks)

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TEE 2006 SA Q9:

When chlorine gas is added to water, the following equilibrium is established:

$$C\ell_2(g) + H_2O(\ell) \rightleftharpoons HOC\ell(aq) + H^+(aq) + C\ell^-(aq) \qquad \Delta H = +ve$$

(a) Write the equilibrium constant expression for this reaction (2 marks)

(b) Complete the following table. Answers should be given as "increases", "decreases" or "no change". (8 marks)

Change made to the equilibrium system	**Immediate effect on rate of forward reaction**	**Effect on equilibrium yield of $HOC\ell(aq)$**
Increase the partial pressure of $C\ell_2(g)$		
Increase the temperature of the system		
Acidify the solution by the addition of nitric acid solution		
Add a suitable catalyst		

TEE 2008 SA Q6:

The following equilibrium is set up by adding solid silver chloride to dilute ammonia solution in three test tubes:

$$AgC\ell(s) + 2\,NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) + C\ell^-(aq)$$

(a) Write an equilibrium constant expression for this equation. (1 mark)

(b) The following changes are made to the equilibrium system. Each change is applied to a separate test tube and equilibrium is re-established. Complete the table below, indicating the changes in the forward reaction rate, and the concentration of $Ag(NH_3)_2^+(aq)$ compared to the original equilibrium system. Use the terms 'increase', 'decrease' or 'no change'.

Also describe what you would observe as equilibrium is re-established in the system.

	At new equilibrium		
Imposed change	**Effect on reaction rate**	**Effect $[Ag(NH_3)_2^+](aq)$**	**Observation**
$NH_3(g)$ is bubbled through the solution			
$NaC\ell(s)$ is added to the solution			
A few drops of concentrated $HNO_3(aq)$ are added to the solution.			

WACE 2014 Q30:

Hydrogen can be made by reacting methane (natural gas) with water (steam). The reaction can form the chemical equilibrium represented below.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3\,H_2(g) + CO(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

State the conditions of temperature and pressure that would optimize the yield of hydrogen at a reasonable rate of reaction. Using collision theory and principles of chemical equilibrium, explain your choice of conditions.

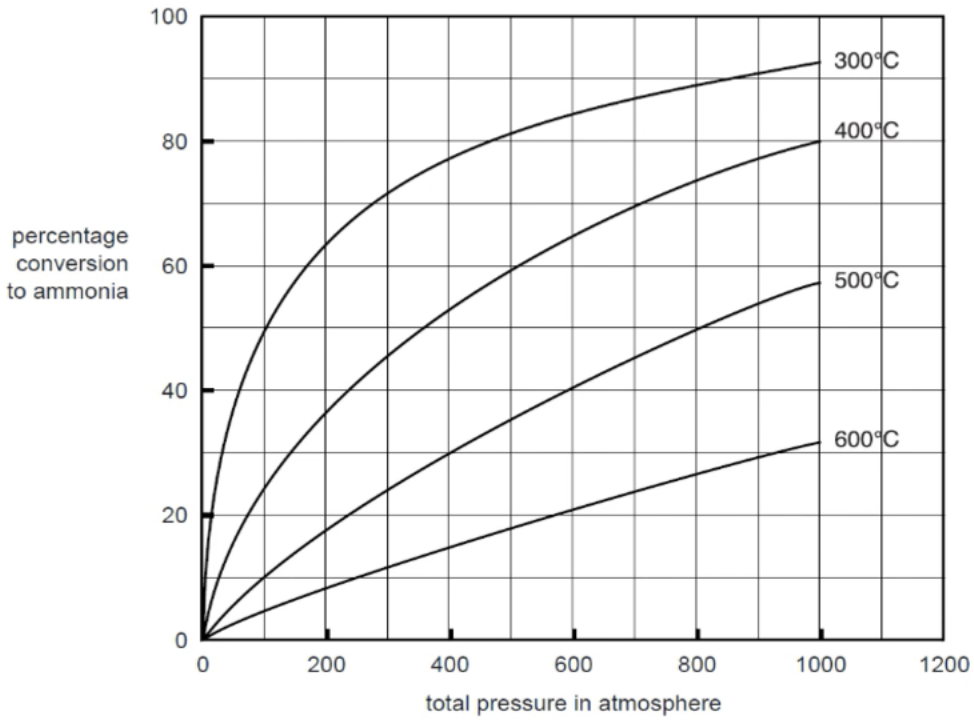
	Optimum conditions	**Explanation**
Temperature	(circle one only) high moderate low (1 mark)	(3 marks)
Pressure	(circle one only) high moderate low (1 mark)	(4 marks)

VCE 2002 Question 4:

Ammonia is prepared industrially from hydrogen and nitrogen in the presence of a suitable catalyst according to the equation:

$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$

The graph below shows the variation of the equilibrium yield of ammonia with pressures at different temperatures.



(a) A particular industrial plant uses a pressure of 300 atm and a temperature of 500 °C. From the graph, determine the percentage yield of ammonia under these conditions. (1 mark)

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(b) State Le Châtelier's principle. (2 marks)

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(c) Deduce from the graph whether the production of ammonia from hydrogen and nitrogen is an exothermic or an endothermic reaction. Explain your reasoning. (2 marks)

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(d) Temperatures less the 400 °C are not used for this industrial reaction even though such temperatures give a greater equilibrium yield of ammonia. Give a possible reason why this is so. (1 mark)

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