Write your name, centre number and candidate number in the boxes below.

Surname	Other names

Centre number | | | | | |

Candidate number | | | | |

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Reversible reactions and equilibrium

Time allowed: 1 hour 30 minutes

Subject code **0620**

Chemistry

Paper 4 (Extended)

You must have: a ruler marked in centimetres and millimetres, a protractor, compasses, a pen, an HB pencil and an eraser.

Total marks

/ 96

Instructions

- Answer every question in the space provided on this paper.
- Write in black or dark blue ink. Pencil may be used for diagrams and graphs.
- Fill in your name, centre number and candidate number above.
- Show your working: a correct method can earn marks even if the answer is wrong.

Information

- This paper has 10 questions worth 96 marks in total.
- The marks for each question or part are shown in brackets, for example [3].

Advice

- Read every question through once before you write anything.
- Use the marks in brackets to judge how long to spend on each part.
- If you finish early, go back and check your working.

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Print at 100% (Actual size) so diagrams keep their real measurements.

1 Ammonia is made by the Haber process.

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

The forward reaction is exothermic.

Typical reaction conditions are:

- finely divided iron catalyst,
- temperature 450 °C,
- pressure 200 atmospheres.

(a) Explain why the catalyst is used as a very fine powder and larger pieces of iron are not used.

.....

.....

..... [2]

(b) Using the above conditions, the equilibrium mixture contains about 15% ammonia.

State two changes to the reaction conditions which would increase the percentage of ammonia at equilibrium.

.....

.....

..... [2]

(c) Suggest why the changes you have described in **(b)** are **not** used in practice.

.....

.....

..... [2]

[Total: 6]

Rates of reaction Click for more variations

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1(a)	large surface area / large area of contact / large surface; more (successful) collisions (between catalyst and gases or between reacting gases) **OR** more active sites **OR** faster reaction / increase rate / increase speed;	**2**	I activation energy Second mark must be comparative
1(b)	decrease temperature / temperature below 450 °C / quoted temperature below 450 °C; increase pressure / pressure above 200 atm / quoted pressure above 200 atm;	**2**	I comments about concentration I low temperature and high pressure. Both answers must be comparative I explanations

1(c)	decreased <u>temperature</u> would reduce rate / reaction slow**<u>er</u>** / too slow; increased <u>pressure</u> expensive / uneconomic / safety risks / leaks / explosions / yield **or** rate good enough at lower pressure / strong pipes needed / thick pipes needed / sturdy pipes needed / requires a lot of energy;	**2**	**A** takes long**<u>er</u>** I slow (unqualified) I answers that do not refer to decreased temperature and increased pressure e.g. it is too expensive unless this is linked with pressure

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2 Iodine reacts with chlorine to form dark brown iodine monochloride.

$$I_2 + Cl_2 \rightarrow 2ICl$$

This reacts with more chlorine to give yellow iodine trichloride.
There is an equilibrium between these iodine chlorides.

$$\underset{\text{dark brown}}{ICl(l)} + Cl_2(g) \rightleftharpoons \underset{\text{yellow}}{ICl_3(s)}$$

(a) Explain what is meant by *equilibrium*.

.....

.....

..... [2]

(b) When the equilibrium mixture is heated it becomes a darker brown colour.
Is the reverse reaction endothermic or exothermic? Give a reason for your choice.

.....

.....

..... [2]

(c) The pressure on the equilibrium mixture is decreased.

(i) How would this affect the position of equilibrium and why?

It would move to the ..... [1]

reason .....

..... [1]

(ii) Describe what you would observe.

.....

..... [1]

[Total: 7]

Reversible reactions and equilibrium Click for more variations

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2 **(a)** rates equal [1]
concentrations do not change / macroscopic properties remain constant [1]
accept amounts do not change

(b) endothermic [1]
cond favoured by high temperatures [1]

(c) **(i)** move to left [1]
cond bigger volume / more moles etc [1]
do not insist on "gas"

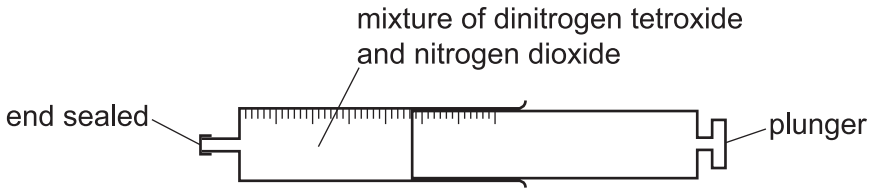
(ii) less yellow solid / more brown liquid [1]
accept yellow to brown / less solid more liquid / goes brown

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3 Dinitrogen tetroxide, N_2O_4, decomposes into nitrogen dioxide, NO_2. The reaction is reversible.

$$\underset{\text{colourless gas}}{N_2O_4(g)} \rightleftharpoons \underset{\text{brown gas}}{2NO_2(g)}$$

A gas syringe containing a mixture of dinitrogen tetroxide and nitrogen dioxide gases was sealed and heated. After reaching equilibrium the mixture was a pale brown colour.



(a) State what is meant by the term *equilibrium*.

.....

.....

..... [2]

(b) The plunger of the gas syringe is pushed in. The temperature does not change. The mixture initially turns darker brown. After a few seconds the mixture turns lighter brown because the equilibrium shifts to the left.

$$\underset{\text{colourless gas}}{N_2O_4(g)} \rightleftharpoons \underset{\text{brown gas}}{2NO_2(g)}$$

(i) Explain why the mixture initially turns darker brown.

..... [1]

(ii) Explain why the position of equilibrium shifts to the left.

..... [1]

(c) The forward reaction is endothermic.

(i) State what happens to the position of equilibrium when the temperature of the mixture is increased.

..... [1]

(ii) State what happens to the rate of the forward reaction and the rate of the backward reaction when the temperature of the mixture is increased.

rate of the forward reaction .....

rate of the backward reaction .....

[2]

[Total: 7]

Reversible reactions and equilibrium Click for more variations

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3(a)	the **rate** of forward reaction equals the rate of the reverse reaction (1) **concentrations** of reactants and products are constant (1)	**2**
3(b)(i)	(increased pressure) nitrogen dioxide **particles** or **molecules** (forced) closer together **OR** same number of nitrogen dioxide **particles** or **molecules** in a smaller volume	**1**
3(b)(ii)	fewer number of gas moles or molecules on left hand side or reactant side (of the equation) **ORA**	**1**
3(c)(i)	shifts to the right	**1**
3(c)(ii)	increase / faster (1) increase / faster (1)	**2**

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4 Ammonia is an important industrial chemical.

(a) (i) Give the electron structure of an atom of nitrogen.

..... [1]

(ii) Use this electronic structure, rather than the valency of nitrogen, to explain why the formula of ammonia is NH_3 not NH_4.

.....

.....

..... [2]

(b) Ammonia is made by the Haber Process.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ forward reaction is exothermic

The percentage of ammonia in the equilibrium mixture varies with conditions.

pressure / atmospheres	100	200	300	400
% ammonia at 300 °C	45	65	72	78
% ammonia at 500 °C	9	18	25	31

The conditions actually used are 200 atmospheres, 450 °C and an iron catalyst.

(i) The original catalyst was platinum. Suggest a reason why it was changed to iron.

..... [1]

(ii) Explain why the highest pressure gives the highest percentage of ammonia in the equilibrium mixture.

.....

..... [2]

(iii) What happens to the unreacted nitrogen and hydrogen?

.....

..... [1]

(iv) State **one** advantage and **one** disadvantage of using a lower temperature.

advantage .....

..... [1]

disadvantage .....

..... [1]

[Total: 9]

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Covalent bonding and simple molecules Click for more variations

4 **(a)** **(i)** nitrogen 2+5 [1]

(ii) needs three electrons [1]
to complete energy level [1]

(b) **(i)** expensive metal / iron cheaper / better catalyst [1]

(ii) high pressure favours side with smaller volume / fewer moles [1]
this is right hand side / product / ammonia side [1]

(iii) recycled / sent over catalyst again [1]
accept used again

(iv) advantage high yield [1]
disadvantage slow reaction rate etc [1]

[Total: 9]

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5 Hydrogen iodide thermally decomposes into iodine and hydrogen. The reaction is reversible.

$$\underset{\text{colourless gas}}{2HI(g)} \rightleftharpoons \underset{\text{purple gas}}{I_2(g)} + \underset{\text{colourless gas}}{H_2(g)}$$

Fig. 4.1 shows a gas syringe containing a mixture of hydrogen iodide, iodine and hydrogen gases. The gas syringe is sealed and the mixture is heated to 300 °C. The mixture of gases reaches equilibrium and is purple.

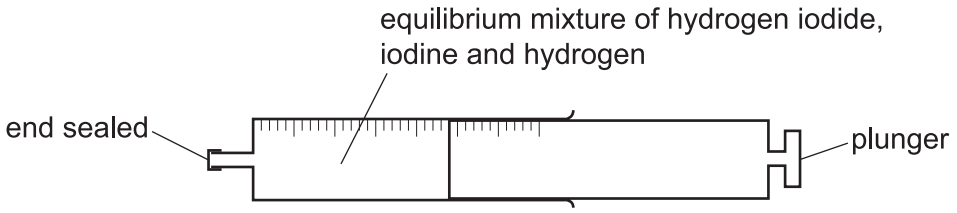


Fig. 4.1

(a) State what is meant by the term equilibrium.

.....

.....

..... [2]

(b) The pressure of the mixture is increased. All other conditions stay the same. The position of equilibrium does **not** change.

The colour of the gaseous mixture turns darker purple.

The temperature remains constant.

$$\underset{\text{colourless gas}}{2HI(g)} \rightleftharpoons \underset{\text{purple gas}}{I_2(g)} + \underset{\text{colourless gas}}{H_2(g)}$$

(i) Explain why the position of equilibrium does **not** change.

.....

..... [1]

(ii) Suggest why the colour of the mixture of gases turns darker purple.

.....

..... [1]

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(c) The temperature of the mixture of gases is decreased. All other conditions stay the same.

The mixture of gases turns lighter purple.

State what can be deduced about the forward reaction from this information.

..... [1]

(d) Deduce the oxidation number of iodine, I, in:

HI .....

I_2. .....

[2]

(e) Methanol is manufactured by reacting carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

The rate of formation of methanol increases when a catalyst is used.

(i) Choose from the list the element that is most likely to be used as the catalyst.

Draw a circle around your chosen answer.

calcium **carbon** **copper** **sodium** **sulfur** [1]

(ii) State the effect on the position of equilibrium when a catalyst is used.

..... [1]

(iii) State the effect that a catalyst has on the activation energy, E_a, of a reaction.

..... [1]

[Total: 10]

Reversible reactions and equilibrium Click for more variations

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5(a)	**M1** The **rate** of forward reaction equals the rate of the reverse reaction(1) **M2 concentrations** of reactants and products are no longer changing(1)	**2**
5(b)(i)	same number of gas moles on both sides of the equilibrium **OR** same number of gas molecules on both sides of the equilibrium	**1**
5(b)(ii)	iodine **particles** or **molecules** (forced) closer together **OR** same number of iodine **particles** or **molecules** in a smaller volume	**1**
5(c)	endothermic	**1**
5(d)	**M1** –1 (1) **M2** zero (1)	**2**
5(e)(i)	copper	**1**
5(e)(ii)	no effect	**1**
5(e)(iii)	(activation energy is) lower	**1**

6 Some chemical reactions are reversible.

(a) Aqueous potassium chromate(VI), K_2CrO_4, is a yellow solution.

Aqueous potassium dichromate(VI), $K_2Cr_2O_7$, is an orange solution.

The two compounds interconvert when the pH of the solution changes.

$$\underset{\text{yellow}}{2K_2CrO_4} + H_2SO_4 \rightleftharpoons \underset{\text{orange}}{K_2Cr_2O_7} + K_2SO_4 + H_2O$$

Solution **Y** is a mixture of aqueous potassium chromate(VI) and aqueous potassium dichromate(VI) at equilibrium.

- Explain, in terms of the position of the equilibrium, what you would **see** if sulfuric acid were added to solution **Y**.

.....

.....

.....

- Explain, in terms of the position of the equilibrium, what you would **see** if sodium hydroxide were added to solution **Y**.

.....

.....

.....

.....

[5]

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(b) Hydrogen can be manufactured using a reversible reaction between methane and steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

At 900 °C, in the presence of a nickel catalyst, the yield of hydrogen is 70%.

(i) What volume of hydrogen is produced from 100 cm^3 of methane under these conditions?

..... cm^3 [2]

Under different conditions, different yields of hydrogen are obtained.

(ii) If the pressure is increased, the yield of hydrogen becomes less than 70%.

Explain why, in terms of the position of the equilibrium.

.....

..... [1]

(iii) If the temperature is decreased, the yield of hydrogen decreases.

What does this information indicate about the reaction between methane and steam?

..... [1]

(iv) Why is a catalyst used in this reaction?

..... [1]

[Total: 10]

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Reversible reactions and equilibrium Click for more variations

6(a)	both colours referred to correctly as observations in both parts of the answer	**1**
	(if sulfuric acid is added to solution **Y**,) equilibrium moves to the right-hand side	**1**
	because the concentration of acid has increased	**1**
	(if sodium hydroxide is added to solution **Y**,) equilibrium moves to the left-hand side	**1**
	because sodium hydroxide reacts with / neutralises sulfuric acid	**1**
6(b)(i)	210 cm^3 **M1** expected volume of hydrogen = 300 cm^3 **M2** 70% of **M1**	**2**
6(b)(ii)	fewer moles / molecules / particles (of gas) on the left-hand side	**1**
6(b)(iii)	endothermic	**1**
6(b)(iv)	increases rate (of reaction)	**1**

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7 Reversible reactions can come to equilibrium. The following are three examples of types of gaseous equilibria.

$A_2(g) + B_2(g) \rightleftharpoons 2AB(g)$ **reaction 1**

$A_2(g) + 3B_2(g) \rightleftharpoons 2AB_3(g)$ **reaction 2**

$2AB_2(g) \rightleftharpoons 2AB(g) + B_2(g)$ **reaction 3**

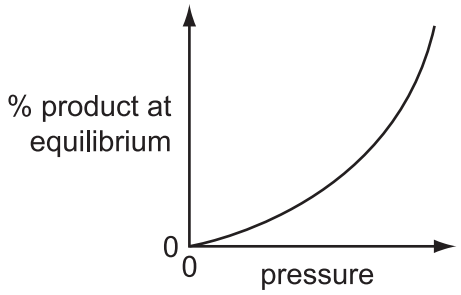
(a) Explain the term *equilibrium*.

.....

..... [2]

(b) The following graphs show how the percentage of products of a reversible reaction at equilibrium could vary with pressure.
For each graph, decide whether the percentage of products decreases, increases or stays the same when the pressure is **increased**, then match each graph to one of the above reactions and give a reason for your choice.

(i)



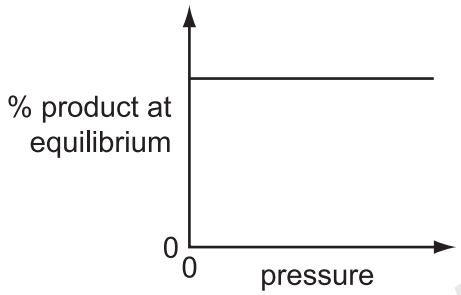
effect on percentage of products .....

reaction .....

reason .....

..... [3]

(ii)



effect on percentage of products .....

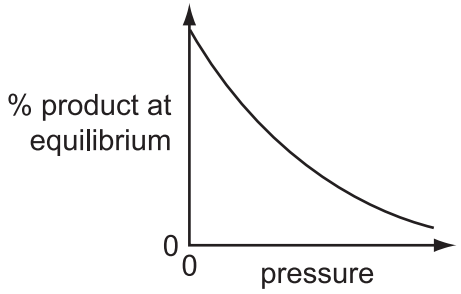
reaction .....

reason .....

..... [3]

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(iii)



effect on percentage of products .....

reaction .....

reason .....

..... [3]

[Total: 11]

Reversible reactions and equilibrium Click for more variations

7 **(a)** rate of forward reaction equals rate of back reaction [1]
concentrations do not change / macroscopic properties remain constant (with time) [1]
accept: amounts

(b) **(i)** increase [1]
reaction 2 [1]
Vr > Vp [1]

(ii) same [1]
reaction 1 [1]
Vr = Vp [1]

(iii) decrease [1]
reaction 3 [1]
Vp > Vr [1]
accept: moles of gas / molecules of gas as an alternative to volume

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8 This question is about ammonia.

(a) Nitrogen reacts with hydrogen to form ammonia in an industrial process.

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

(i) Name this industrial process.

..... [1]

(ii) State the meaning of the symbol $\rightleftharpoons$.

..... [1]

(iii) State the conditions used in this industrial process. Include units.

temperature .....

pressure .....

[2]

(iv) Name the catalyst used in this industrial process.

..... [1]

(v) If the pressure is increased, the yield of ammonia increases.

Explain why, in terms of equilibrium.

.....

.....

..... [2]

(vi) If the temperature is increased, the rate of reaction increases.

Explain why, in terms of particles.

.....

.....

.....

.....

..... [3]

(b) Ammonia reacts with sulfuric acid to make a compound which is used as a fertiliser.

Write the chemical equation for the reaction between ammonia and sulfuric acid.

..... [2]

[Total: 12]

Haber process and Contact process Click for more variations

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Reduced to 77% to fit the page (wider than A4).

8(a)(i)	Haber	**1**
8(a)(ii)	reversible / equilibrium	**1**
8(a)(iii)	450 °C (1) 200 atm (1)	**2**
8(a)(iv)	iron / Fe	**1**
8(a)(v)	equilibrium **shifts / moves** in forwards direction (1) fewer molecules / moles (of gas) on RHS (1)	**2**
8(a)(vi)	particles have more energy (1) more collisions (between particles) occur per second / per unit time (1) a greater percentage / proportion / fraction of collisions (of particles) are successful / have energy above activation energy / have energy equal to activation energy (1)	**3**
8(b)	$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$ $(NH_4)_2SO_4$ (1) correct equation (1)	**2**

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9 Methane reacts with steam to produce hydrogen gas.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +200\,kJ/mol$$

The reaction takes place at 1000 °C and 100 kPa pressure.

(a) The reaction is reversible and reaches an equilibrium in a closed system.

State **two** features of an equilibrium.

1 .....

2 .....

[2]

(b) State and explain, in terms of equilibrium, what happens to the concentration of hydrogen when:

(i) the pressure is increased

.....

..... [2]

(ii) the temperature is increased

.....

..... [2]

(iii) a catalyst is used.

.....

..... [2]

(c) Methane is a greenhouse gas which contributes to global warming.

(i) Name a greenhouse gas found in clean, dry air.

..... [1]

(ii) Explain, in terms of thermal energy, how greenhouse gases cause global warming.

.....

.....

.....

.....

..... [3]

[Total: 12]

Air, pollution and climate change Click for more variations

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9(a)	**M1** the rate of forward reaction equals (the rate of the) reverse reaction (1) **M2** the concentrations of reactants and products are no longer changing (1)	**2**
9(b)(i)	**M1** concentration decreases (1) **M2** position of equilibrium shifts to left **AND** fewer moles of gas on left hand side (1)	**2**
9(b)(ii)	**M1** concentration increases (1) **M2** position of equilibrium shifts to the right **AND** forward reaction is endothermic (1)	**2**
9(b)(iii)	**M1** no change (1) **M2** catalysts do not affect position of equilibrium (1)	**2**
9(c)(i)	carbon dioxide	**1**
9(c)(ii)	**M1** greenhouse gases absorb thermal energy (from the Earth) (1) **M2 and M3** one mark each for any two of: • energy (from the sun) absorbed by Earth's surface • Earth emits or reflects thermal energy • (greenhouse gases) reduces or stops thermal energy loss (into space) • increasing in amount of greenhouse gas results in a higher atmospheric temperature	**3**

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10 Chalcopyrite, $FeCuS_2$, is used in the manufacture of sulfuric acid in the Contact process.

(a) In the first stage of the process, chalcopyrite reacts with oxygen in the air to produce sulfur dioxide, SO_2, iron(III) oxide and copper(II) oxide.

Complete the chemical equation for the reaction of $FeCuS_2$ with oxygen.

$$4FeCuS_2 + 13O_2 \rightarrow \text{.....} + \text{.....} + \text{.....}$$ [2]

(b) Sulfur dioxide is then converted to sulfur trioxide.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

The reaction is exothermic. It is also an equilibrium.

(i) State **two** features of an equilibrium.

1 .....

2 .....
[2]

(ii) State the temperature and pressure used in this reaction.
Include units.

- temperature .....
- pressure .....
[2]

(iii) Name the catalyst used.

..... [1]

(iv) Explain why a catalyst is used.

..... [1]

(v) Describe and explain, in terms of equilibrium, what happens when the temperature is increased.

.....

..... [2]

(c) Concentrated sulfuric acid is a dehydrating agent.

When glucose is dehydrated, carbon and one other product are formed.

Complete the equation to show the dehydration of glucose, $C_6H_{12}O_6$.

$$C_6H_{12}O_6 \rightarrow \text{.....}C + \text{.....}$$ [2]

[Total: 12]

Haber process and Contact process Click for more variations

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10(a)	$(4FeCuS\ 13O_2) \rightarrow 2Fe_2O_3 + 4CuO + 8SO_2$ Fe_2O_3 and CuO as a product (1) Equation fully correct (1)	**2**
10(b)(i)	**M1** rate of forward reaction = rate of reverse reaction (1) **M2** concentration of reactants and products are constant (1)	**2**
10(b)(ii)	**M1** 450 °C (1) **M2** 1-2 atm (1)	**2**
10(b)(iii)	vanadium(V) oxide	**1**
10(b)(iv)	increase rate of reaction	**1**
10(b)(v)	**M1** equilibrium shifts to left hand side (1) **M2** forward reaction is exothermic (1)	**2**
10(c)	$C_6H_{12}O_6 \rightarrow 6C + 6H_2O$ H_2O (1) balance (1)	**2**

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