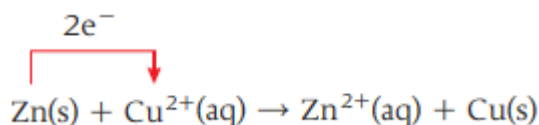


Section 1: Voltaic Cells

Electrochemistry is the study of the redox processes by which chemical energy is converted to electrical energy and vice versa.

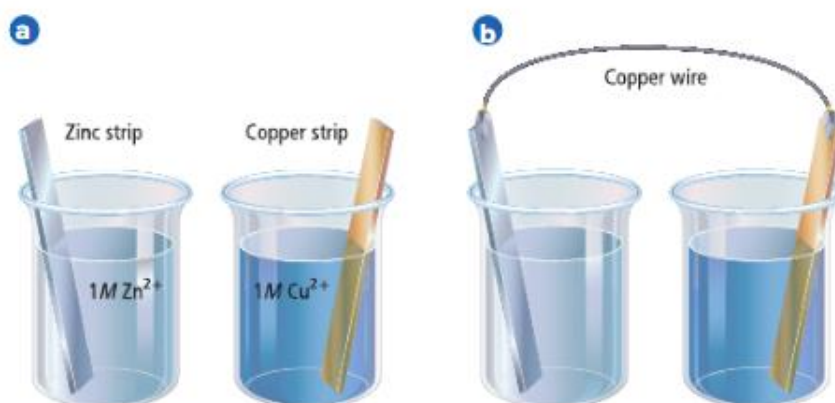


Write the two half-reactions make up this redox process:

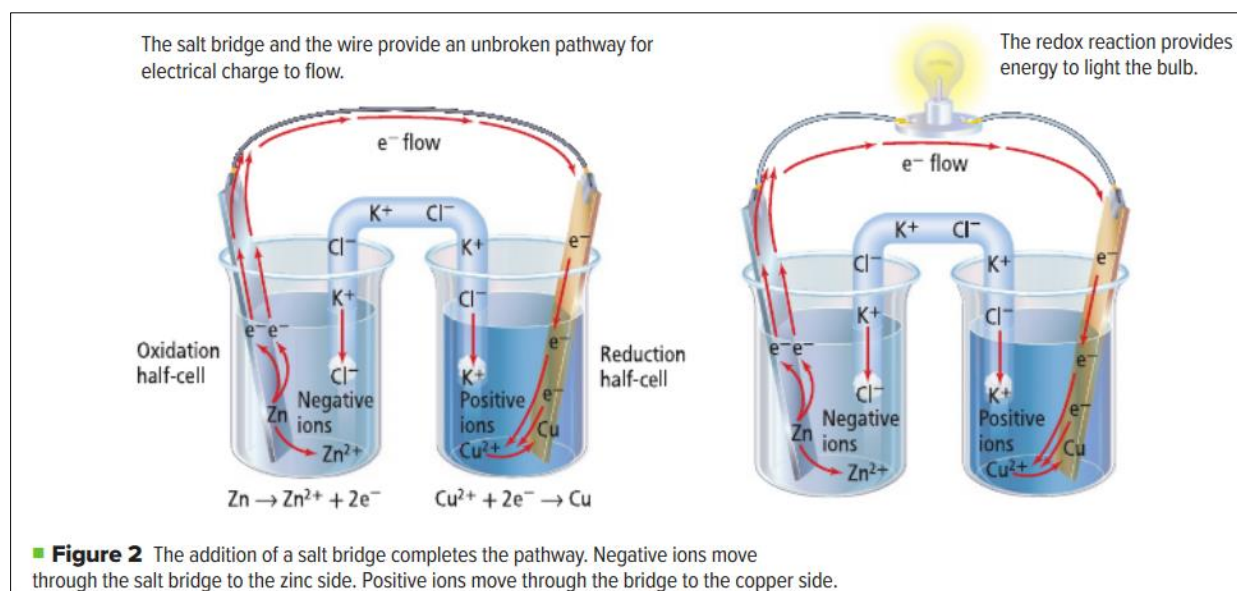
Oxidation half-reaction:

Reduction half-reaction:

Figure 1 These containers are constructed and arranged so that zinc will be oxidized on one side, while copper ions will be reduced on the other. In **a**, zinc metal is immersed in 1M zinc sulfate solution, and copper metal in 1M copper sulfate. In **b**, a wire joining the zinc and copper strips provides a pathway for the flow of electrons, but the pathway is not complete. Electron transfer is still not possible.



When the metal strips are placed in their solutions, oxidation begins at the zinc strip and reduction begins at the copper strip—but these reactions cannot continue. **The reason is** that as zinc is oxidized, positive zinc ions build up around the zinc electrode. As copper in the copper sulfate solution is reduced, negative sulfate ions build up around the copper electrode. The buildup of charges stops any further reaction.



A **salt bridge** is a pathway to allow the passage of ions from one side to another. It consists of a tube containing a conducting solution of a soluble salt, such as KCl, held in place by an agar gel or other permeable plug. Ions can move through the plug, but the solutions in the two beakers cannot mix.

When the connecting metal wire and the salt bridge are in place, the spontaneous redox reaction begins. Electrons flow through the wire from the oxidation half-reaction to the reduction half-reaction, while positive and negative ions move through the salt bridge.

The flow of electrons through the wire and the flow of ions through the salt bridge make up the **electric current**.

Electrochemical cells

An **electrochemical cell** is an apparatus that uses a redox reaction to produce electrical energy or uses electrical energy to cause a chemical reaction.

A **voltaic cell** is a type of electrochemical cell that converts chemical energy to electrical energy by a spontaneous redox reaction.

Chemistry of Voltaic Cells

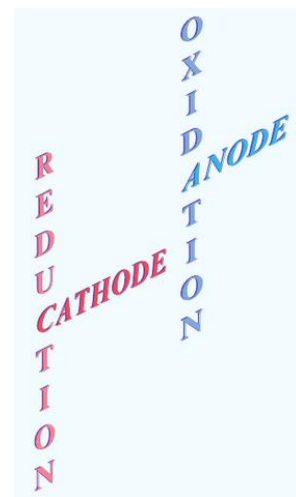
An electrochemical cell consists of two parts called **half-cells**, in which the separate oxidation and reduction reactions take place. Each half-cell contains an electrode and a solution containing ions.

An **electrode** is an electrically conductive material, usually a metallic strip or graphite, that conducts electrons into and out of the solution in the half cell.

In Figure 2, the beaker with the electrode is where the oxidation half of the redox reaction takes place. The beaker with the electrode is where the reduction half of the reaction takes place.

The reaction that takes place in each half-cell is called a half-cell reaction.

The electrode where oxidation takes place is the **anode**. The electrode where reduction takes place is the **cathode**.



Question: Identify which of the beakers in Figure 2 contains the anode.

Voltaic cells and energy

In electrochemistry, **electric potential energy** is a measure of the amount of current that can be generated from a voltaic cell to do work.

Electric charge can flow between two points only when a difference in electric potential energy exists between the two points. **What are these two points?**

The electromotive force (EMF) pushes the electrons toward the cathode. This force is due to the difference in electric potential energy between the two electrodes and is referred to as the **cell potential**.

A **volt** (V) is a unit used to measure cell potential.

The **electric potential difference** of a voltaic cell is an indication of the energy that is available to move electrons from the anode to the cathode.

The energy of the electrons flowing from the anode to the cathode in a voltaic cell is determined by the difference in electric potential energy between the two electrodes.

In redox terms, the voltage of a cell is determined by comparing the difference in the tendency of the two electrode materials to accept electrons. The greater the difference, the greater the potential energy difference between the two electrodes and the larger the voltage of the cell will be.

In the zinc-copper cell, under standard conditions, copper (II) ions at the cathode accept electrons more readily than the zinc ions at the anode. Thus, the redox reaction occurs spontaneously only when the electrons flow from the zinc to the copper.

Calculating Electrochemical Cell Potentials

The tendency of a substance to gain electrons is its **reduction potential**.

The reduction potential of an electrode cannot be determined directly because the reduction half-reaction must be coupled with an oxidation half-reaction.

The standard hydrogen electrode

This electrode can act as an oxidation half-reaction or a reduction half-reaction, depending on the half-cell to which it is connected.

Half-cell potentials

Chemists have measured the potential when each half-cell was connected to a standard hydrogen half-cell.

All the half-reactions in **Table 1** are written as reductions.

The half-reaction with the lower reduction potential will proceed in the opposite direction and will be an oxidation reaction.

These measures must be under standard conditions, that is, immersed in a 1M solution of its ions at 25°C and 1 atm.

The superscript zero in the notation E^0 is a shorthand way of indicating “measured under standard conditions.”

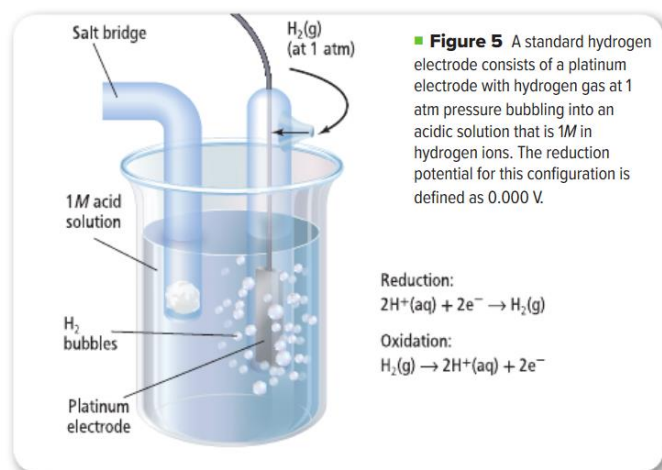


Table 20.1

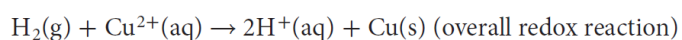
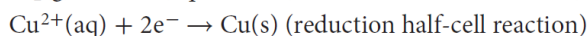
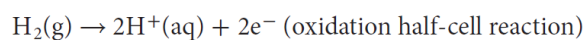
Standard Reduction Potentials

Half-Reaction	E^0 (V)	Half-Reaction	E^0 (V)
$\text{Li}^+ + \text{e}^- \rightarrow \text{Li}$	-3.0401	$\text{Cu}^{2+} + \text{e}^- \rightarrow \text{Cu}^+$	+0.153
$\text{Ca}^{2+} + 2\text{e}^- \rightarrow \text{Ca}$	-2.868	$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$	+0.3419
$\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$	-2.71	$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$	+0.401
$\text{Mg}^{2+} + 2\text{e}^- \rightarrow \text{Mg}$	-2.372	$\text{I}_2 + 2\text{e}^- \rightarrow 2\text{I}^-$	+0.5355
$\text{Be}^{2+} + 2\text{e}^- \rightarrow \text{Be}$	-1.847	$\text{Fe}^{3+} + \text{e}^- \rightarrow \text{Fe}^{2+}$	+0.771
$\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$	-1.662	$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightarrow \text{NO}_2 + \text{H}_2\text{O}$	+0.775
$\text{Mn}^{2+} + 2\text{e}^- \rightarrow \text{Mn}$	-1.185	$\text{Hg}_2^{2+} + 2\text{e}^- \rightarrow 2\text{Hg}$	+0.7973
$\text{Cr}^{2+} + 2\text{e}^- \rightarrow \text{Cr}$	-0.913	$\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$	+0.7996
$2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$	-0.8277	$\text{Hg}^{2+} + 2\text{e}^- \rightarrow \text{Hg}$	+0.851
$\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$	-0.7618	$2\text{Hg}_2^{2+} + 2\text{e}^- \rightarrow \text{Hg}_2^{2+}$	+0.920
$\text{Cr}^{3+} + 3\text{e}^- \rightarrow \text{Cr}$	-0.744	$\text{NO}_3^- + 4\text{H}^+ + 3\text{e}^- \rightarrow \text{NO} + 2\text{H}_2\text{O}$	+0.957
$\text{S} + 2\text{e}^- \rightarrow \text{S}^{2-}$	-0.47627	$\text{Br}_2(\text{l}) + 2\text{e}^- \rightarrow 2\text{Br}^-$	+1.066
$\text{Fe}^{2+} + 2\text{e}^- \rightarrow \text{Fe}$	-0.447	$\text{Pt}^{2+} + 2\text{e}^- \rightarrow \text{Pt}$	+1.18
$\text{Cd}^{2+} + 2\text{e}^- \rightarrow \text{Cd}$	-0.4030	$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$	+1.229
$\text{PbI}_2 + 2\text{e}^- \rightarrow \text{Pb} + 2\text{I}^-$	-0.365	$\text{Cl}_2 + 2\text{e}^- \rightarrow 2\text{Cl}^-$	+1.35827
$\text{PbSO}_4 + 2\text{e}^- \rightarrow \text{Pb} + \text{SO}_4^{2-}$	-0.3588	$\text{Au}^{3+} + 3\text{e}^- \rightarrow \text{Au}$	+1.498
$\text{Co}^{2+} + 2\text{e}^- \rightarrow \text{Co}$	-0.28	$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.507
$\text{Ni}^{2+} + 2\text{e}^- \rightarrow \text{Ni}$	-0.257	$\text{Au}^+ + \text{e}^- \rightarrow \text{Au}$	+1.692
$\text{Sn}^{2+} + 2\text{e}^- \rightarrow \text{Sn}$	-0.1375	$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}$	+1.776
$\text{Pb}^{2+} + 2\text{e}^- \rightarrow \text{Pb}$	-0.1262	$\text{Co}^{3+} + \text{e}^- \rightarrow \text{Co}^{2+}$	+1.92
$\text{Fe}^{3+} + 3\text{e}^- \rightarrow \text{Fe}$	-0.037	$\text{S}_2\text{O}_8^{2-} + 2\text{e}^- \rightarrow 2\text{SO}_4^{2-}$	+2.010
$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$	0.0000	$\text{F}_2 + 2\text{e}^- \rightarrow 2\text{F}^-$	+2.866

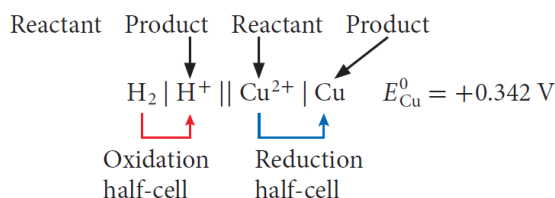
Determining electrochemical cell potentials

In Cell **a**, electrons flow from the electrode to the
the oxidation happened at and the reduction at
The E^0 , measured by a voltmeter, is +0.342 V.

The positive voltage indicates that Cu^{2+} ions at the copper electrode accept electrons more readily than do H^+ ions at the hydrogen electrode.



This reaction can be written in a form called **cell notation**.



In Cell **b**, electrons flow from the electrode to the
the oxidation happened at and the reduction at
The E^0 , measured by a voltmeter, is -0.762 V..

The negative voltage indicates that
.....

Complete:

oxidation half-cell reaction:

reduction half-cell reaction:

overall redox cell reaction:

Now write the cell notation:

To calculate the electric potential of a voltaic cell consisting of a **copper** electrode and a **zinc** electrode, combine the copper and zinc half-cells as a voltaic cell.

Because reduction occurs at the copper electrode and oxidation occurs at the zinc electrode, the E^0 values are substituted as follows.

$$\begin{aligned} E_{\text{cell}}^0 &= E_{\text{Cu}^{2+}|\text{Cu}}^0 - E_{\text{Zn}^{2+}|\text{Zn}}^0 \\ &= +0.342 \text{ V} - (-0.762 \text{ V}) \\ &= +1.104 \text{ V} \end{aligned}$$

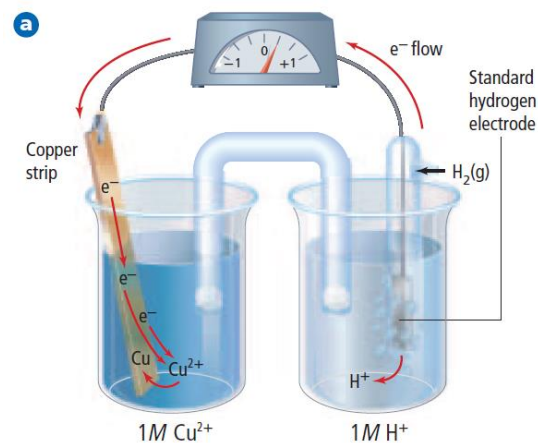
Do you need to reverse the sign of the oxidation half-reaction? Why?

Graph Check

The potential difference between the zinc and copper electrodes is

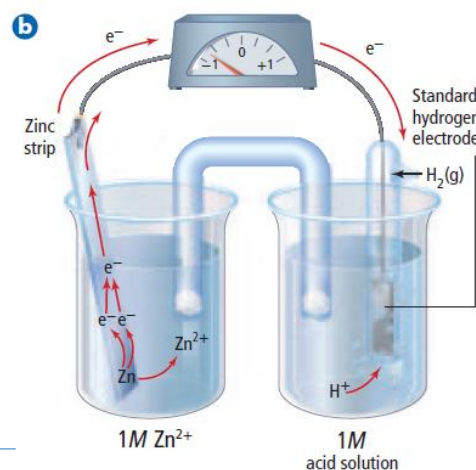
Identify the metal, copper or zinc, that is easier to oxidize than hydrogen.

Challenge: write the cell notation for this cell.



The double vertical line (||) represents

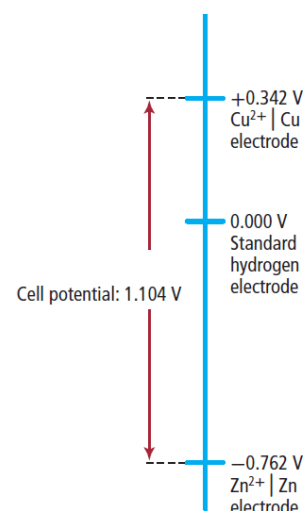
..... and



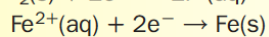
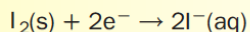
Formula for Cell Potential

$$E_{\text{cell}}^0 = E_{\text{cathode}}^0 - E_{\text{anode}}^0$$

$$E_{\text{cell}}^0 = E_{\text{reduction}}^0 - E_{\text{oxidation}}^0$$

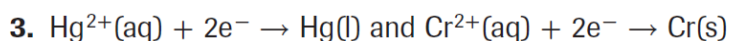
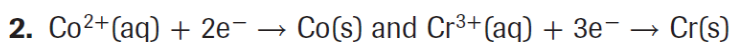
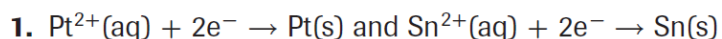


CALCULATE A CELL POTENTIAL The following reduction half-reactions represent the half-cells of a voltaic cell.

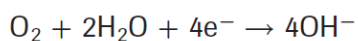
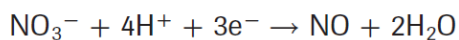


Determine the overall cell reaction and the standard cell potential.
Describe the cell using cell notation.

For each of these pairs of half-reactions, write the balanced equation for the overall cell reaction, and calculate the standard cell potential. Describe the reaction using cell notation. Refer to Chapter 19 to review writing and balancing redox equations.



4. **Challenge** Write the balanced equation for the cell reaction and calculate the standard cell potential for the reaction that occurs when these half-cells are connected. Describe the reaction using cell notation.

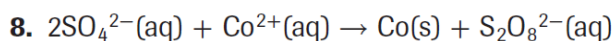
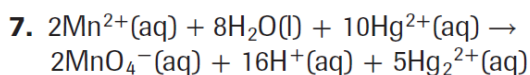
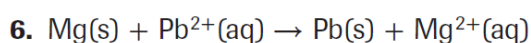
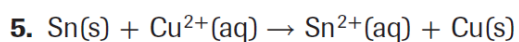


Using Standard Reduction Potentials to indicate spontaneity

To predict whether any proposed redox reaction will occur spontaneously:

- 1- write the process in the form of half-reactions.
- 2- look up the reduction potential of each.
- 3- Use the values to calculate the potential of a voltaic cell operating with these two half-cell reactions.
- 4- If the calculated potential is positive, the reaction is spontaneous. If the value is negative, the reaction is not spontaneous.
- 5- the reverse of a nonspontaneous reaction will occur because it will have a positive cell voltage, which means that the reverse reaction is spontaneous.

Calculate the cell potential to determine if each of the following balanced redox reactions is spontaneous as written. Use **Table 20.1** to help you determine the correct half-reactions.

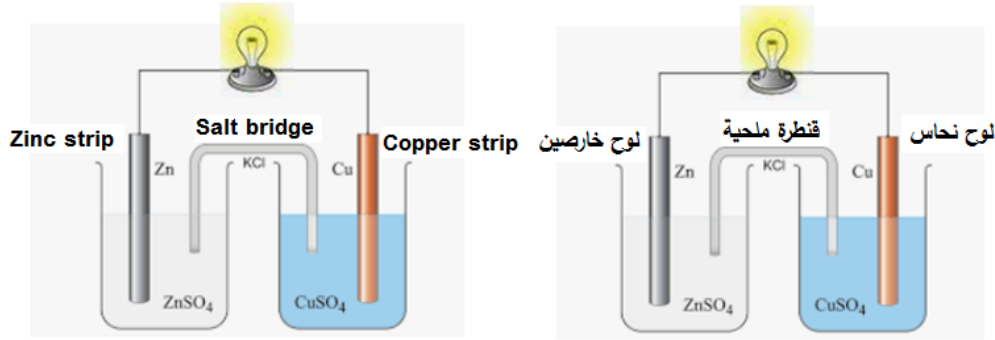


9. **Challenge** Using **Table 20.1**, write the equation and determine the cell voltage (E^0) for the following cell. Is the reaction spontaneous?



In the voltaic cell shown in the figure below, which of the following statements is true?

في الخلية الفولتية الموضحة في الشكل أدناه، أي العبارات التالية صحيحة؟



Uses electrical energy to cause a chemical reaction

تستخدم الطاقة الكهربائية لإحداث تفاعل كيميائي

Electrons move through the salt bridge to the copper side

تتحرك الإلكترونات عبر القنطرة الملحية وصولاً إلى جهة النحاس

Positive zinc ions build up around the zinc electrode

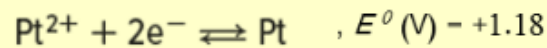
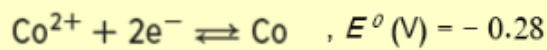
تتراكم أيونات الخارصين الموجبة حول القطب الكهربائي للخارصين

The wire can serve as a pathway for electrons to flow from the zinc strip to the copper strip

يعمل السلك كمسار لانتقال الإلكترونات من لوح الخارصين إلى لوح النحاس

The following reduction half-reactions represent the half-cells of a voltaic cell. which of the following is correct?

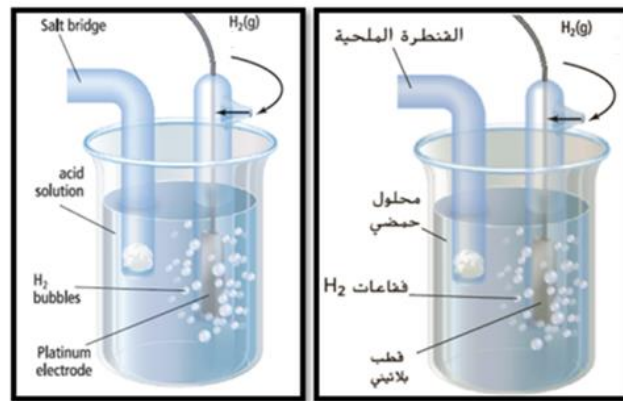
تمثل تفاعلات الاختزال النصفية التالية الخلايا النصفية للخلية الفولتية، أي مما يأتي صحيح؟



	الأنود Anode	الكاثود cathode	جهد الخلية (E°) Electrochemical Cell Potential (E°)	نوع التفاعل Reaction Type
A	Pt	Co	+ 0.9 V	تلقائي Spontaneous
B	Co	Pt	+ 1.46 V	تلقائي Spontaneous
C	Pt	Co	- 0.9 V	غير تلقائي Nonspontaneous
D	Co	Pt	- 1.46 V	غير تلقائي Nonspontaneous

Which of the following is true for the standard hydrogen electrode shown in the figure below?

أي مما يأتي صحيح فيما يتعلق بقطب الهيدروجين القياسي الموضح في الشكل أدناه؟



It is the cathode in all the voltaic cells in which it is connected

يكون كاثودًا في جميع الخلايا الفولتية التي يُوصَل فيها

It is the anode in all the voltaic cells in which it is connected

يكون أنودًا في جميع الخلايا الفولتية التي يُوصَل فيها

The reduction potential of this electrode is 0.000V when the concentration of the acid solution is 1 M and hydrogen gas is pumped under pressure 1 atm and the temperature is maintained at 25°C

جهد اختزال هذا القطب يساوي 0.000V عندما يكون تركيز محلول الحمض 1 M ويضخ غاز الهيدروجين تحت ضغط 1 atm وتبقى درجة الحرارة ثابتة عند 25°C

The reduction potential of this electrode is 0.000V at all conditions

جهد اختزال هذا القطب يساوي 0.000V عند جميع الظروف

Regarding the standard hydrogen electrode in the figure below. Which of the following is **correct**?

فيما يتعلق بقطب الهيدروجين القياسي في الشكل أدناه.

أي مما يأتي **صحيح**؟



It will be an anode when connected to Zn | Zn²⁺ electrode

يكون أنودًا عند توصيله مع قطب Zn | Zn²⁺ ☐

It will be a cathode when connected to Cu|Cu²⁺ electrode

يكون كاثودًا عند توصيله مع قطب Cu|Cu²⁺ ☐

The standard reduction potential (E⁰), of the standard hydrogen electrode is defined as 1.104 V

جهد الاختزال القياسي (E⁰) لقطب الهيدروجين يساوي 1.104 V ☐

The standard reduction potential (E⁰), of the standard hydrogen electrode is defined as 0.000 V

جهد الاختزال القياسي (E⁰) لقطب الهيدروجين يساوي 0.000 V ☐

In the figure below, what do the two half-cells need so that you can convert chemical energy into electrical energy?

في الشكل أدناه، ما الذي يحتاجه نصف الخلية حتى يمكنك تحويل الطاقة الكيميائية إلى طاقة كهربائية؟



Only connecting the zinc and copper strips with a metal wire to serve as a pathway for electrons to flow

فقط ربط لوجي الخارصين والنحاس بسلك نحاسي لتوفير مسار لنقل الإلكترونات

A salt bridge and a metal wire to provide an unbroken pathway for electrical charge to flow

قطرة ملحية وسلك نحاسي معًا لتوفير مسار غير منقطع لانتقال الشحنات الكهربائية

A salt bridge to serve as a pathway for electrons to flow and a metal wire to serve as a pathway for ions to flow

قطرة ملحية لنقل الإلكترونات وسلك نحاسي لنقل الأيونات

Only a salt bridge to serve as a pathway for ions to flow

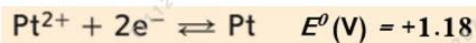
فقط قطرة ملحية لتوفير مسار لنقل الأيونات

The voltaic half-cell expressed by the following reaction has been connected with one of the half-cells shown in the table below, and the standard cell potential found to be (+3.89 V).

تم توصيل نصف الخلية الفولتية الذي يُعبر عنه التفاعل التالي مع أحد أنصاف الخلايا الواردة في الجدول أدناه، ووجد أن الجهد القياسي للخلية الناتجة هو (+3.89 V).

What is the half-cell connected?

ما نصف الخلية الذي تم توصيله؟



Half reaction نصف التفاعل	$E^{\circ}(\text{V})$
$\text{Na}^{+} + \text{e}^{-} \rightleftharpoons \text{Na}$	-2.71
$\text{Mn}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Mn}$	-1.185
$\text{Cr}^{3+} + 3\text{e}^{-} \rightleftharpoons \text{Cr}$	-0.744
$\text{Fe}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Fe}$	-0.447

The following reduction half-reactions represent the half-cells of a voltaic cell.

تمثل تفاعلات الاختزال النصفية التالية الخلايا النصفية للخلية الفولتية. ما الجهد القياسي للخلية؟

What is the standard cell potential?



(+0.667 V)

(+3.027 V)

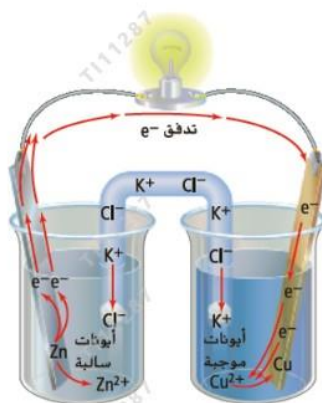
(-3.027 V)

(-0.667 V)

In the figure below, which of the following is **not**

في الشكل أدناه، أي مما يأتي **ليست** من وظائف القنطرة الملحية؟

a function of the salt bridge?



Prevents the mixing of the two solutions

○ تمنع اختلاط المحلولين

Prevents ions building up around the electrodes

○ تمنع تراكم الأيونات حول القطبين

Allows the passage of ions from one side to another

○ تسمح بمرور الأيونات من جهة إلى أخرى

Allows the passage of electrons from one side to another

○ تسمح بمرور الإلكترونات من جهة إلى أخرى

Regarding the figure below. What are the conditions

فيما يتعلق بالشكل أدناه. أي مما يأتي هي الظروف الواجب توفرها

required to make sure that the standard hydrogen

حتى يكون جهد الاختزال القياسي (E^0) لقطب الهيدروجين مساوياً

electrode potential (E^0) equals **0.000 V** ?

؟ **0.000 V**



بقاء درجة الحرارة ثابتة عند 25 °C	1
The temperature is maintained at 25 °C	
ضخ غاز الهيدروجين (H_2) في المحلول عند ضغط 1 atm	2
Hydrogen gas (H_2) at a pressure of 1 atm is bubbled into the solution	
وجود محلول حمض الهيدروكلوريك (HCl) الذي يحتوي على أيونات الهيدروجين بتركيز 1 M	3
The presence of hydrochloric acid (HCl) solution that has a hydrogen-ion concentration of 1 M .	

3 only

3 فقط

1, 2

1 و 2

1, 2, and 3

1 و 2 و 3

1 only

1 فقط