

## Exam of Physical and Chemical Analyses of Materials

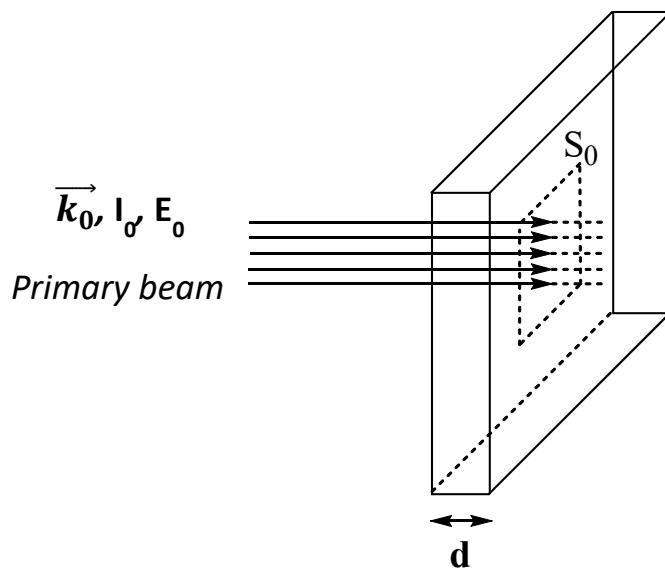
**June 2024**

**Duration: 3 hours**

### I. Interaction beam-matter

#### I.1. Interaction beam-matter: matter excitation

During a physical or a chemical analysis of a material, one has to take into account the interaction of a beam with the matter across a surface  $S_0$ . The primary beam is characterized by a wave vector  $\vec{k}_0$ , a beam energy  $E_0$  and a beam intensity  $I_0$ . After interacting with the matter, the primary beam is affected by the different events.



Complete the table by ticking the box(es) which correspond(s) to the parameter(s) mainly affected by the following events:

	$\vec{k}_0$	$\ \vec{k}_0\ $	$E_0$	$I_0$
<b>Absorption</b>				
<b>Elastic scattering</b>				
<b>Inelastic scattering</b>				

Complete the following table related to the use of electrons and X-Rays as primary beams:

Event	Nature of the primary beam	Type of scattering	Target
<b>Rayleigh</b>			
<b>Compton</b>			
<b>Bremsstrahlung</b>			
<b>Diffraction</b>			
<b>Ionisation</b>			

Indicate if the following statements are true or false:

	<b>true</b>	<b>false</b>
▪ The modulus of the wave vector is not linked to the energy of its associated particle.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The cross-section for the Compton effect increases with the energy of the X-Ray photons.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The Bremsstrahlung generates specific X-Rays.	<input type="checkbox"/>	<input type="checkbox"/>
▪ Diffraction occurs when the wavelength of the incoming beam and the diffracting object have almost the same size.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The ionisation of a target atom always takes place at the K level.	<input type="checkbox"/>	<input type="checkbox"/>

## I.2. Interaction beam-matter: matter emission

Complete the following table while considering inelastic scatterings leading to the ionisation of the matter. Indicate if the emission is directly caused by the primary beam (direct emission) or consecutive to the matter relaxation (indirect emission) by ticking the correct(s) box(es).

<b>Primary beam</b>	<b>Emission type</b>	<b>Direct emission</b>	<b>Indirect emission</b>
<b>X-Rays</b>			
<b>Electrons</b>			

In material analysis, the emission types listed above are used for either microscopic or analytical purposes.

Among the emission types listed above, highlight the one(s) which possesses/possess an energy related to the energy of the primary beam.



Among the emitted beams listed above, highlight the one(s) which possesses/possess an energy only related to the chemical nature of the emitting element.



Among the emitted beams listed above, highlight the one(s) for which it is not clearly possible to correlate its energy to neither the energy of the primary beam nor the chemical nature of the emitting element.



Indicate if the following statements are true or false:

	true	false
▪ The probability of X-Ray emission is greater for light chemical elements than for heavy ones.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The emission of X-Rays follows strict selection rules.	<input type="checkbox"/>	<input type="checkbox"/>
▪ Auger electrons can be produced by either an X-ray or an electron primary beam.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The kinetic energy of Auger electrons is correlated to the energy of the primary beam.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The emission of Auger electrons follows strict selection rules.	<input type="checkbox"/>	<input type="checkbox"/>

### I.3. Interaction beam-matter: X-rays production

XRF and XPS instruments share the same primary beam, that is X-Ray photons. Using a drawing, describe how X-Rays are produced. Indicate on the drawing the mechanism(s) that produces/produce X-rays during the interaction beam-matter using a simple Bohr atom model. Draw the resulting X-ray spectrum: the intensity  $I$  of the X-Ray photons as a function of the wavelength  $\lambda$ .

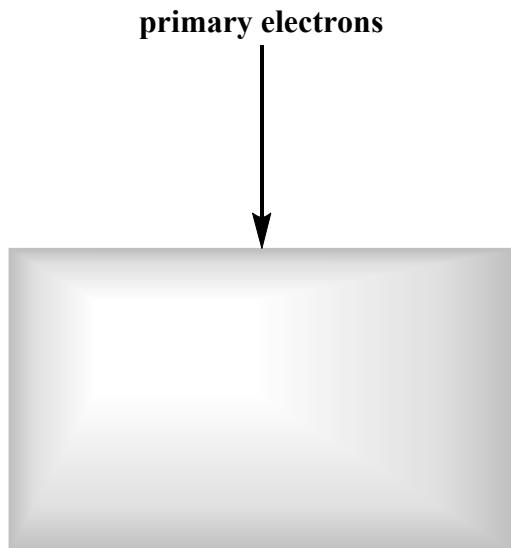
## II. Physical characterization of materials

### II.1. Electron microscopy

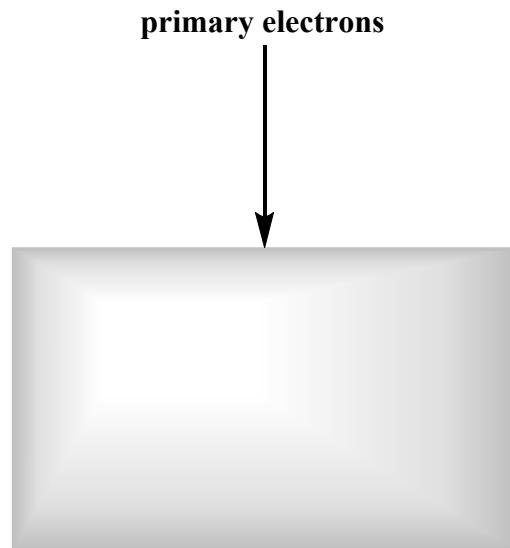
SEM (Scheme A) and TEM (Scheme B) are both related to electron microscopy. Complete the following drawings with:

- the trajectory of the electrons in the studied sample and the specific probed sample volume
- the events recorded for each microscopy and the emission zones of these events

**Scheme A: SEM**



**Scheme B: TEM**



Based on the previous question, complete the following table and thick the correct answer(s).

	TEM	SEM
<b>Typical beam energy range</b>		
<b>Lateral resolution range</b>		
<b>Scanning mode</b>	<input type="checkbox"/> yes <input type="checkbox"/> no	<input type="checkbox"/> yes <input type="checkbox"/> no
<b>Sample features</b>	<input type="checkbox"/> size $\leq$ 3 mm <input type="checkbox"/> thickness < 100 nm <input type="checkbox"/> high surface conductivity <input type="checkbox"/> flat surface <input type="checkbox"/> specific preparation	<input type="checkbox"/> size $\leq$ 3 mm <input type="checkbox"/> thickness < 100 nm <input type="checkbox"/> high surface conductivity <input type="checkbox"/> flat surface <input type="checkbox"/> specific preparation
<b>Sample holder</b>	<input type="checkbox"/> conducting holder <input type="checkbox"/> no requirement	<input type="checkbox"/> conducting holder <input type="checkbox"/> no requirement
<b>Analysed signals</b>		
<b>Type(s) of image</b>		

What is the main effect while reducing the energy of the electron primary beam?

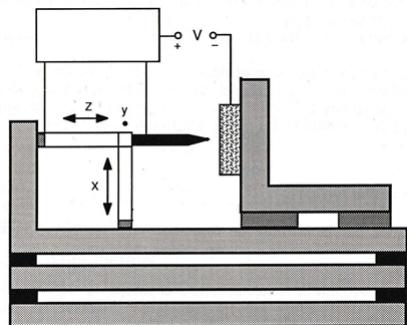
In which type of electron microscopy and for which reason(s) it may sometimes be of interest to decrease the energy of the primary electron beam?

Indicate if the following statements are true or false:

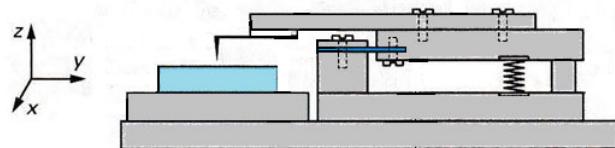
	true	false
▪ With TEM, it is possible to obtain morphological information on nanoparticles deposited on an electron transparent material.	<input type="checkbox"/>	<input type="checkbox"/>
▪ With TEM, it is possible to obtain morphological information on a bulky material.	<input type="checkbox"/>	<input type="checkbox"/>
▪ With TEM, it is possible to obtain structural information on an amorphous material.	<input type="checkbox"/>	<input type="checkbox"/>
▪ With TEM, it is possible to obtain topographical information using the method of replicas.	<input type="checkbox"/>	<input type="checkbox"/>
▪ For SEM studies, the sample must be prepared using the Formvar method.	<input type="checkbox"/>	<input type="checkbox"/>
▪ In SEM, decreasing the beam energy enhance the production of backscattered electrons.	<input type="checkbox"/>	<input type="checkbox"/>
▪ In SEM, a sample coating made of gold enhances the production of secondary electrons.	<input type="checkbox"/>	<input type="checkbox"/>
▪ In SEM, charging effects appear when the electrons at the surface of the material are correctly drained.	<input type="checkbox"/>	<input type="checkbox"/>

## II.2. Scanning probe microscopy

Below are depicted the technical schemes of an AFM and a STM microscopes. Appoint each microscope to the corresponding scheme.



A:



B:

Indicate on the schemes above the location of the sample, the tip, the cantilever and the mobile arm.

Complete the following table by ticking the correct box(es):

	STM	AFM
Tip directly mounted on a mobile arm		
Tip indirectly coupled to a mobile arm		
Tip polarised against the studied material		
Setting up a tunnelling current between the tip and the studied sample		
Setting up a contact between the tip and the studied sample		
Sensitive to the forces involved between the tip and the material		
Sensitive to the electronic states of a material		
Analysis of conductors and semiconductors		
Analysis of insulators		
Lateral resolution at the Angstrom level		
Lateral resolution at the nanometre level		

What is the difference between an STM image obtained from a positive mode (the tip is positively polarised against the sample) and from a negative mode (the tip is negatively polarised against the sample)?

Which scanning probe microscopy would you choose to study a biological membrane?

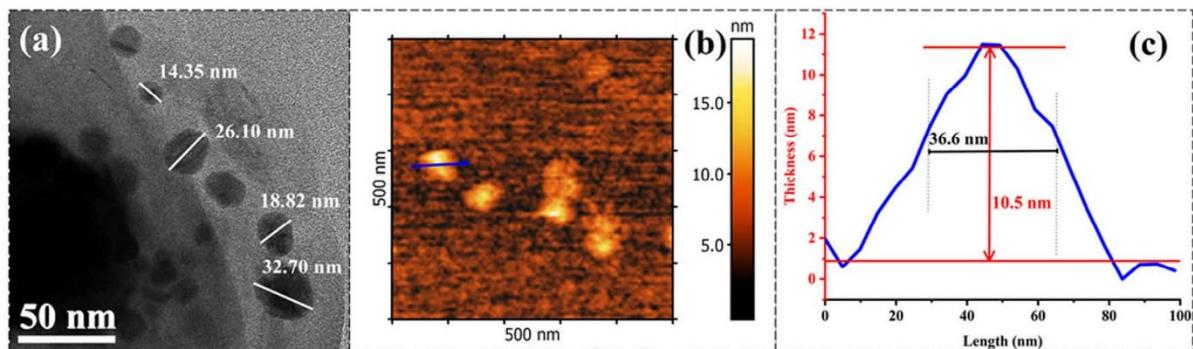
With which mode are you going to operate? Base your answer on a brief description of the chosen mode while pointing out its highlights regarding the nature of a biological membrane.

Indicate if the following statements are true or false:

	<b>true</b>	<b>false</b>
▪ STM is always performed under vacuum or under inert atmosphere.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The STM tip is still along the x and y axes.	<input type="checkbox"/>	<input type="checkbox"/>
▪ STM can be performed at constant height.	<input type="checkbox"/>	<input type="checkbox"/>
▪ STM can be performed at a constant tip oscillation amplitude.	<input type="checkbox"/>	<input type="checkbox"/>
▪ AFM is mostly used for morphological studies.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The AFM tip is moving along the scanned surface.	<input type="checkbox"/>	<input type="checkbox"/>
▪ AFM performed in contact mode is dedicated to the study of soft surfaces.	<input type="checkbox"/>	<input type="checkbox"/>
▪ The STM tip can oscillate at a given frequency.	<input type="checkbox"/>	<input type="checkbox"/>
▪ When AFM is performed in tapping mode, the tip is in intermittent contact with the scanned surface.	<input type="checkbox"/>	<input type="checkbox"/>

### II.3. TEM versus STM

STM and TEM achieve almost the same lateral resolution and then can be compared. Below are displayed the analysis of MgB<sub>2</sub> nanoparticles by TEM and STM:



**A)** TEM image of the synthetised nanoparticles, **B)** STM image of the synthetised nanoparticles, **C)** resulting topography of a given synthetised nanoparticle.

What kind of TEM image is displayed in figure **A**?

The STM image was recorded at a constant tunnelling current of 2 nA. Briefly describe this operating mode.

Briefly describe the TEM and STM pictures in terms of morphology and topography.

The topographic profile displayed on figure **c** relies on which technic: TEM or STM?

### III. Chemical characterization of materials

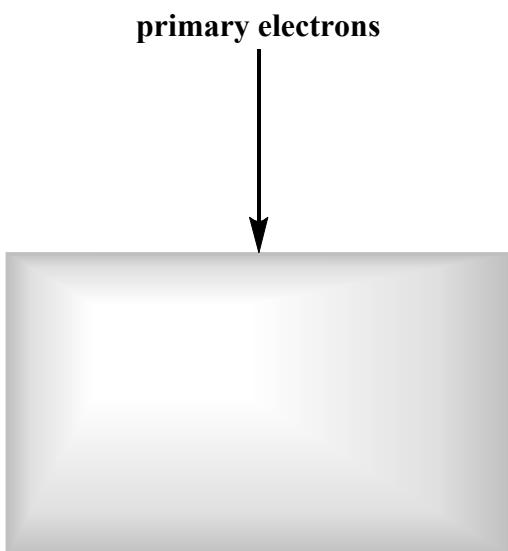
#### III.1. General

Chemical analysis of a material are mainly carried out using electron or X-ray sources.

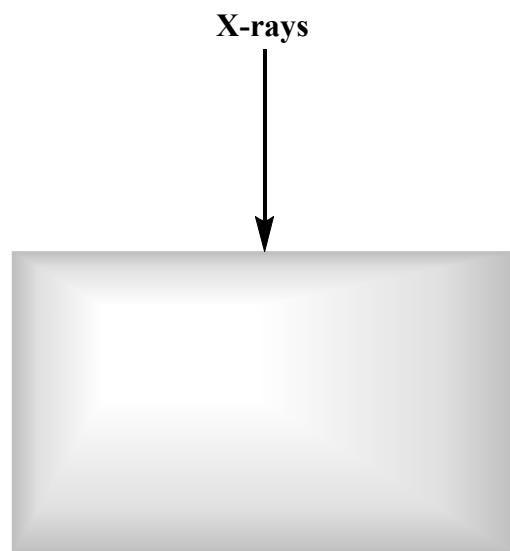
Complete the following drawings with:

- the trajectory of the primary beam in the studied sample and the specific probed sample volume (in both cases, the primary beam does not emerge from the sample).
- all the events related to analytical purposes and the emission zones of these events.

**Scheme A**



**Scheme B**



Indicate if the following statements are true or false:

	true	false
▪ Secondary electrons are considered for chemical analysis.	<input type="checkbox"/>	<input type="checkbox"/>
▪ Backscattered electrons are considered for chemical analysis.	<input type="checkbox"/>	<input type="checkbox"/>
▪ Useful electrons in chemical analysis are emitted from the surface of the material.	<input type="checkbox"/>	<input type="checkbox"/>
▪ For chemical analysis, the brightness of the electron source is of most importance compared to its stability.	<input type="checkbox"/>	<input type="checkbox"/>
▪ For chemical analysis Hard X-Ray sources are required.	<input type="checkbox"/>	<input type="checkbox"/>

In analytical chemistry, the proposed analytical method must meet two different features. What are these two features?

### III.2. Bulk and surface analyses

Complete the following table by ticking the correct box for each chemical analysis:

	Semi-Bulk	Bulk	Surface
XRFS			
XPS			
XRMA			
AES			

Complete the following table by ticking the correct box for each chemical analysis:

	X-rays as primary beam	Electrons as primary beam
XRFS		
XPS		
XRMA		
AES		

Complete the following table by filling the boxes:

	Background signal	Recorded signal	Side signal(s)
XRFS			
XPS			
XRMA			
AES			

XRMA can be achieved thanks to an SEM or using a specific apparatus.

Give the name of this specific apparatus.

What are the differences between the electron sources of these two apparatus?

Briefly describe the spectrometer associated to each apparatus?

### III.3. XRFS vs XPS

XPS and XRFS share the same exciting beam. Nevertheless, the two X-Ray sources are different.

Briefly explain the main spectral differences that exist between these two sources and why it is necessary to have these different spectral features.

Which of these two methods is the most sensitive to the chemical nature of the neighbours of an analysed element?

Which parameter represents the influence of the neighbourhood of an analysed element?

On a XPS spectrum, one can observe two different types of signals. How one can distinguish both?

One of these two technics must follow a correction process to achieve a good quantitative accuracy. Which technic is concerned by these so-called matrix effects? For the concerned technic, give the set of correction parameters that one must applied to meet a proper quantitative analysis.

# TABLEAU PÉRIODIQUE DES ÉLÉMENS

<http://www.periodni.com/fr/>

GROUPE  
1 IA  
1 H  
HYDROGÈNE  
2 IA  
2 Li  
LITHIUM  
11 22.990 12 24.305

PERIODE  
1  
1 1.0079  
2  
3 6.941 4 9.0122  
2 Li  
LITHIUM BERYLLIUM  
11 22.990 12 24.305

MASSE ATOMIQUE RELATIVE (1)  
GROUPE IUPAC  
13  
NOMBRE ATOMIQUE 13  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
3 Na MAGNÉSIUM 3  
SODIUM MAGNÉSIUM 3  
19 39.086 20 40.078  
4 K CALCIUM 3  
POURASSIUM CALCIUM 3  
37 35.468 38 37.62  
5 Rb STRONTIUM 4  
RUBIDIUM STRONTIUM 4  
55 132.91 56 137.33  
6 Cs BARYUM 5  
CÉSIUM BARYUM 5  
87 (223) 88 (226)  
7 Fr FRANCUM 6  
FRANCUM RADIUM 6

GROUPE CAS  
13  
5 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
4 VB 4  
SCANDIUM SCANDIUM 4  
39 88.906 40 91.224  
5 Rb STRONTIUM 4  
RUBIDIUM STRONTIUM 4  
55 132.91 56 137.33  
6 Cs BARYUM 5  
CÉSIUM BARYUM 5  
87 (223) 88 (226)  
7 Fr FRANCUM 6  
FRANCUM RADIUM 6

GROUPE CAS  
5 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
5 VB 5  
TITANIUM TITANIUM 5  
41 92.906 42 95.96  
5 Rb STRONTIUM 5  
RUBIDIUM STRONTIUM 5  
55 132.91 56 137.33  
6 Cs BARYUM 6  
CÉSIUM BARYUM 6  
87 (223) 88 (226)  
7 Fr FRANCUM 6  
FRANCUM RADIUM 6

GROUPE CAS  
6 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
6 VB 6  
VANADIUM VANADIUM 6  
41 92.906 42 95.96  
5 Rb STRONTIUM 6  
RUBIDIUM STRONTIUM 6  
55 132.91 56 137.33  
6 Cs BARYUM 6  
CÉSIUM BARYUM 6  
87 (223) 88 (226)  
7 Fr FRANCUM 6  
FRANCUM RADIUM 6

GROUPE CAS  
7 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
7 VB 7  
CHROMIUM CHROMIUM 7  
42 95.96 43 (98)  
5 Rb STRONTIUM 7  
RUBIDIUM STRONTIUM 7  
55 132.91 56 137.33  
6 Cs BARYUM 7  
CÉSIUM BARYUM 7  
87 (223) 88 (226)  
7 Fr FRANCUM 7  
FRANCUM RADIUM 7

GROUPE CAS  
8 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
8 VB 8  
MOLYBDÈNE MOLYBDÈNE 8  
73 180.95 74 183.84  
5 Rb STRONTIUM 8  
RUBIDIUM STRONTIUM 8  
55 132.91 56 137.33  
6 Cs BARYUM 8  
CÉSIUM BARYUM 8  
87 (223) 88 (226)  
7 Fr FRANCUM 8  
FRANCUM RADIUM 8

GROUPE CAS  
9 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
9 VB 9  
TUNGSTÈNE TUNGSTÈNE 9  
76 190.23 75 186.21  
5 Rb STRONTIUM 9  
RUBIDIUM STRONTIUM 9  
55 132.91 56 137.33  
6 Cs BARYUM 9  
CÉSIUM BARYUM 9  
87 (223) 88 (226)  
7 Fr FRANCUM 9  
FRANCUM RADIUM 9

GROUPE CAS  
10 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
10 VB 10  
RHÉNIUM RHÉNIUM 10  
77 192.22 76 190.23  
5 Rb STRONTIUM 10  
RUBIDIUM STRONTIUM 10  
55 132.91 56 137.33  
6 Cs BARYUM 10  
CÉSIUM BARYUM 10  
87 (223) 88 (226)  
7 Fr FRANCUM 10  
FRANCUM RADIUM 10

GROUPE CAS  
11 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
11 VB 11  
OSMIUM OSMIUM 11  
78 195.08 79 196.97  
5 Rb STRONTIUM 11  
RUBIDIUM STRONTIUM 11  
55 132.91 56 137.33  
6 Cs BARYUM 11  
CÉSIUM BARYUM 11  
87 (223) 88 (226)  
7 Fr FRANCUM 11  
FRANCUM RADIUM 11

GROUPE CAS  
12 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
12 VB 12  
RHODIUM RHODIUM 12  
79 196.97 80 200.59  
5 Rb STRONTIUM 12  
RUBIDIUM STRONTIUM 12  
55 132.91 56 137.33  
6 Cs BARYUM 12  
CÉSIUM BARYUM 12  
87 (223) 88 (226)  
7 Fr FRANCUM 12  
FRANCUM RADIUM 12

GROUPE CAS  
13 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
13 VB 13  
RHÉNIUM RHÉNIUM 13  
80 200.59 81 204.38  
5 Rb STRONTIUM 13  
RUBIDIUM STRONTIUM 13  
55 132.91 56 137.33  
6 Cs BARYUM 13  
CÉSIUM BARYUM 13  
87 (223) 88 (226)  
7 Fr FRANCUM 13  
FRANCUM RADIUM 13

GROUPE CAS  
14 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
14 VB 14  
RHÉNIUM RHÉNIUM 14  
81 204.38 82 207.2  
5 Rb STRONTIUM 14  
RUBIDIUM STRONTIUM 14  
55 132.91 56 137.33  
6 Cs BARYUM 14  
CÉSIUM BARYUM 14  
87 (223) 88 (226)  
7 Fr FRANCUM 14  
FRANCUM RADIUM 14

GROUPE CAS  
15 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
15 VB 15  
RHÉNIUM RHÉNIUM 15  
82 207.2 83 208.98  
5 Rb STRONTIUM 15  
RUBIDIUM STRONTIUM 15  
55 132.91 56 137.33  
6 Cs BARYUM 15  
CÉSIUM BARYUM 15  
87 (223) 88 (226)  
7 Fr FRANCUM 15  
FRANCUM RADIUM 15

GROUPE CAS  
16 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
16 VB 16  
RHÉNIUM RHÉNIUM 16  
83 208.98 84 (209)  
5 Rb STRONTIUM 16  
RUBIDIUM STRONTIUM 16  
55 132.91 56 137.33  
6 Cs BARYUM 16  
CÉSIUM BARYUM 16  
87 (223) 88 (226)  
7 Fr FRANCUM 16  
FRANCUM RADIUM 16

GROUPE CAS  
17 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
17 VB 17  
RHÉNIUM RHÉNIUM 17  
84 (209) 85 (210)  
5 Rb STRONTIUM 17  
RUBIDIUM STRONTIUM 17  
55 132.91 56 137.33  
6 Cs BARYUM 17  
CÉSIUM BARYUM 17  
87 (223) 88 (226)  
7 Fr FRANCUM 17  
FRANCUM RADIUM 17

GROUPE CAS  
18 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
18 VB 18  
RHÉNIUM RHÉNIUM 18  
85 (210) 86 (222)  
5 Rb STRONTIUM 18  
RUBIDIUM STRONTIUM 18  
55 132.91 56 137.33  
6 Cs BARYUM 18  
CÉSIUM BARYUM 18  
87 (223) 88 (226)  
7 Fr FRANCUM 18  
FRANCUM RADIUM 18

GROUPE CAS  
19 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
19 VB 19  
RHÉNIUM RHÉNIUM 19  
86 (222) 87 (224)  
5 Rb STRONTIUM 19  
RUBIDIUM STRONTIUM 19  
55 132.91 56 137.33  
6 Cs BARYUM 19  
CÉSIUM BARYUM 19  
87 (223) 88 (226)  
7 Fr FRANCUM 19  
FRANCUM RADIUM 19

GROUPE CAS  
20 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
20 VB 20  
RHÉNIUM RHÉNIUM 20  
87 (224) 88 (225)  
5 Rb STRONTIUM 20  
RUBIDIUM STRONTIUM 20  
55 132.91 56 137.33  
6 Cs BARYUM 20  
CÉSIUM BARYUM 20  
87 (223) 88 (226)  
7 Fr FRANCUM 20  
FRANCUM RADIUM 20

GROUPE CAS  
21 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
21 VB 21  
RHÉNIUM RHÉNIUM 21  
88 (225) 89 (226)  
5 Rb STRONTIUM 21  
RUBIDIUM STRONTIUM 21  
55 132.91 56 137.33  
6 Cs BARYUM 21  
CÉSIUM BARYUM 21  
87 (223) 88 (226)  
7 Fr FRANCUM 21  
FRANCUM RADIUM 21

GROUPE CAS  
22 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
22 VB 22  
RHÉNIUM RHÉNIUM 22  
89 (226) 90 (227)  
5 Rb STRONTIUM 22  
RUBIDIUM STRONTIUM 22  
55 132.91 56 137.33  
6 Cs BARYUM 22  
CÉSIUM BARYUM 22  
87 (223) 88 (226)  
7 Fr FRANCUM 22  
FRANCUM RADIUM 22

GROUPE CAS  
23 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
23 VB 23  
RHÉNIUM RHÉNIUM 23  
90 (227) 91 (231)  
5 Rb STRONTIUM 23  
RUBIDIUM STRONTIUM 23  
55 132.91 56 137.33  
6 Cs BARYUM 23  
CÉSIUM BARYUM 23  
87 (223) 88 (226)  
7 Fr FRANCUM 23  
FRANCUM RADIUM 23

GROUPE CAS  
24 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
24 VB 24  
RHÉNIUM RHÉNIUM 24  
91 (231) 92 (238)  
5 Rb STRONTIUM 24  
RUBIDIUM STRONTIUM 24  
55 132.91 56 137.33  
6 Cs BARYUM 24  
CÉSIUM BARYUM 24  
87 (223) 88 (226)  
7 Fr FRANCUM 24  
FRANCUM RADIUM 24

GROUPE CAS  
25 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
25 VB 25  
RHÉNIUM RHÉNIUM 25  
92 (238) 93 (238)  
5 Rb STRONTIUM 25  
RUBIDIUM STRONTIUM 25  
55 132.91 56 137.33  
6 Cs BARYUM 25  
CÉSIUM BARYUM 25  
87 (223) 88 (226)  
7 Fr FRANCUM 25  
FRANCUM RADIUM 25

GROUPE CAS  
26 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
26 VB 26  
RHÉNIUM RHÉNIUM 26  
93 (238) 94 (237)  
5 Rb STRONTIUM 26  
RUBIDIUM STRONTIUM 26  
55 132.91 56 137.33  
6 Cs BARYUM 26  
CÉSIUM BARYUM 26  
87 (223) 88 (226)  
7 Fr FRANCUM 26  
FRANCUM RADIUM 26

GROUPE CAS  
27 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
27 VB 27  
RHÉNIUM RHÉNIUM 27  
94 (237) 95 (244)  
5 Rb STRONTIUM 27  
RUBIDIUM STRONTIUM 27  
55 132.91 56 137.33  
6 Cs BARYUM 27  
CÉSIUM BARYUM 27  
87 (223) 88 (226)  
7 Fr FRANCUM 27  
FRANCUM RADIUM 27

GROUPE CAS  
28 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
28 VB 28  
RHÉNIUM RHÉNIUM 28  
95 (244) 96 (243)  
5 Rb STRONTIUM 28  
RUBIDIUM STRONTIUM 28  
55 132.91 56 137.33  
6 Cs BARYUM 28  
CÉSIUM BARYUM 28  
87 (223) 88 (226)  
7 Fr FRANCUM 28  
FRANCUM RADIUM 28

GROUPE CAS  
29 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
29 VB 29  
RHÉNIUM RHÉNIUM 29  
96 (243) 97 (247)  
5 Rb STRONTIUM 29  
RUBIDIUM STRONTIUM 29  
55 132.91 56 137.33  
6 Cs BARYUM 29  
CÉSIUM BARYUM 29  
87 (223) 88 (226)  
7 Fr FRANCUM 29  
FRANCUM RADIUM 29

GROUPE CAS  
30 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
30 VB 30  
RHÉNIUM RHÉNIUM 30  
97 (247) 98 (247)  
5 Rb STRONTIUM 30  
RUBIDIUM STRONTIUM 30  
55 132.91 56 137.33  
6 Cs BARYUM 30  
CÉSIUM BARYUM 30  
87 (223) 88 (226)  
7 Fr FRANCUM 30  
FRANCUM RADIUM 30

GROUPE CAS  
31 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
31 VB 31  
RHÉNIUM RHÉNIUM 31  
98 (247) 99 (251)  
5 Rb STRONTIUM 31  
RUBIDIUM STRONTIUM 31  
55 132.91 56 137.33  
6 Cs BARYUM 31  
CÉSIUM BARYUM 31  
87 (223) 88 (226)  
7 Fr FRANCUM 31  
FRANCUM RADIUM 31

GROUPE CAS  
32 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
32 VB 32  
RHÉNIUM RHÉNIUM 32  
99 (251) 100 (257)  
5 Rb STRONTIUM 32  
RUBIDIUM STRONTIUM 32  
55 132.91 56 137.33  
6 Cs BARYUM 32  
CÉSIUM BARYUM 32  
87 (223) 88 (226)  
7 Fr FRANCUM 32  
FRANCUM RADIUM 32

GROUPE CAS  
33 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
33 VB 33  
RHÉNIUM RHÉNIUM 33  
100 (257) 101 (258)  
5 Rb STRONTIUM 33  
RUBIDIUM STRONTIUM 33  
55 132.91 56 137.33  
6 Cs BARYUM 33  
CÉSIUM BARYUM 33  
87 (223) 88 (226)  
7 Fr FRANCUM 33  
FRANCUM RADIUM 33

GROUPE CAS  
34 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
34 VB 34  
RHÉNIUM RHÉNIUM 34  
101 (258) 102 (259)  
5 Rb STRONTIUM 34  
RUBIDIUM STRONTIUM 34  
55 132.91 56 137.33  
6 Cs BARYUM 34  
CÉSIUM BARYUM 34  
87 (223) 88 (226)  
7 Fr FRANCUM 34  
FRANCUM RADIUM 34

GROUPE CAS  
35 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
35 VB 35  
RHÉNIUM RHÉNIUM 35  
102 (259) 103 (262)  
5 Rb STRONTIUM 35  
RUBIDIUM STRONTIUM 35  
55 132.91 56 137.33  
6 Cs BARYUM 35  
CÉSIUM BARYUM 35  
87 (223) 88 (226)  
7 Fr FRANCUM 35  
FRANCUM RADIUM 35

GROUPE CAS  
36 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
36 VB 36  
RHÉNIUM RHÉNIUM 36  
103 (262) 104 (265)  
5 Rb STRONTIUM 36  
RUBIDIUM STRONTIUM 36  
55 132.91 56 137.33  
6 Cs BARYUM 36  
CÉSIUM BARYUM 36  
87 (223) 88 (226)  
7 Fr FRANCUM 36  
FRANCUM RADIUM 36

GROUPE CAS  
37 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
37 VB 37  
RHÉNIUM RHÉNIUM 37  
104 (265) 105 (268)  
5 Rb STRONTIUM 37  
RUBIDIUM STRONTIUM 37  
55 132.91 56 137.33  
6 Cs BARYUM 37  
CÉSIUM BARYUM 37  
87 (223) 88 (226)  
7 Fr FRANCUM 37  
FRANCUM RADIUM 37

GROUPE CAS  
38 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
38 VB 38  
RHÉNIUM RHÉNIUM 38  
105 (268) 106 (271)  
5 Rb STRONTIUM 38  
RUBIDIUM STRONTIUM 38  
55 132.91 56 137.33  
6 Cs BARYUM 38  
CÉSIUM BARYUM 38  
87 (223) 88 (226)  
7 Fr FRANCUM 38  
FRANCUM RADIUM 38

GROUPE CAS  
39 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
39 VB 39  
RHÉNIUM RHÉNIUM 39  
106 (271) 107 (272)  
5 Rb STRONTIUM 39  
RUBIDIUM STRONTIUM 39  
55 132.91 56 137.33  
6 Cs BARYUM 39  
CÉSIUM BARYUM 39  
87 (223) 88 (226)  
7 Fr FRANCUM 39  
FRANCUM RADIUM 39

GROUPE CAS  
40 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
40 VB 40  
RHÉNIUM RHÉNIUM 40  
107 (272) 108 (277)  
5 Rb STRONTIUM 40  
RUBIDIUM STRONTIUM 40  
55 132.91 56 137.33  
6 Cs BARYUM 40  
CÉSIUM BARYUM 40  
87 (223) 88 (226)  
7 Fr FRANCUM 40  
FRANCUM RADIUM 40

GROUPE CAS  
41 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
41 VB 41  
RHÉNIUM RHÉNIUM 41  
108 (277) 109 (276)  
5 Rb STRONTIUM 41  
RUBIDIUM STRONTIUM 41  
55 132.91 56 137.33  
6 Cs BARYUM 41  
CÉSIUM BARYUM 41  
87 (223) 88 (226)  
7 Fr FRANCUM 41  
FRANCUM RADIUM 41

GROUPE CAS  
42 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
42 VB 42  
RHÉNIUM RHÉNIUM 42  
109 (276) 110 (281)  
5 Rb STRONTIUM 42  
RUBIDIUM STRONTIUM 42  
55 132.91 56 137.33  
6 Cs BARYUM 42  
CÉSIUM BARYUM 42  
87 (223) 88 (226)  
7 Fr FRANCUM 42  
FRANCUM RADIUM 42

GROUPE CAS  
43 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
43 VB 43  
RHÉNIUM RHÉNIUM 43  
110 (281) 111 (286)  
5 Rb STRONTIUM 43  
RUBIDIUM STRONTIUM 43  
55 132.91 56 137.33  
6 Cs BARYUM 43  
CÉSIUM BARYUM 43  
87 (223) 88 (226)  
7 Fr FRANCUM 43  
FRANCUM RADIUM 43

GROUPE CAS  
44 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
44 VB 44  
RHÉNIUM RHÉNIUM 44  
111 (286) 112 (285)  
5 Rb STRONTIUM 44  
RUBIDIUM STRONTIUM 44  
55 132.91 56 137.33  
6 Cs BARYUM 44  
CÉSIUM BARYUM 44  
87 (223) 88 (226)  
7 Fr FRANCUM 44  
FRANCUM RADIUM 44

GROUPE CAS  
45 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
45 VB 45  
RHÉNIUM RHÉNIUM 45  
112 (285) 113 (284)  
5 Rb STRONTIUM 45  
RUBIDIUM STRONTIUM 45  
55 132.91 56 137.33  
6 Cs BARYUM 45  
CÉSIUM BARYUM 45  
87 (223) 88 (226)  
7 Fr FRANCUM 45  
FRANCUM RADIUM 45

GROUPE CAS  
46 10.811  
SYNTHÈSE BORE

NOM DE L'ÉLÉMENT  
46 VB 46  
RHÉNIUM RHÉNIUM 46  
113 (284) 114 (287)  
5