



THE SOLUBLE SALTS IN THE BUILT HERITAGE

Stone materials and conservation of the built heritage – The soluble salts – BR 1



Principal ions of the harmful soluble salts:

Cations	Anions
Na ⁺ (sodium)	CO ₃ ⁻ (carbonate)
K ⁺ (potassium)	HCO ₃ ⁻ (hydrogencarbonate)
Ca ⁺⁺ (calcium)	SO ₄ ⁻ (sulphate)
Mg ⁺⁺ (magnesium)	NO ₃ ⁻ (nitrate)
NH ₄ ⁺ (ammonium)	Cl ⁻ (chloride)
	C ₂ O ₄ ⁻ (oxalate)

Stone materials and conservation of the built heritage – The soluble salts – BR 2



Principal soluble salts in building stones (in CH):

	English	French	
Chlorides	halite	"	NaCl
	sylvite	sylvine	KCl
Nitrates	niter	salpêtre, nitre	KNO ₃
	nitronatrite ammonium nitrate	" , nitratine nitrate d'ammonium	NaNO ₃ NH ₄ NO ₃ (pH<7)
Sulphates	thenardite	thénardite	Na ₂ SO ₄
	mirabilite	"	Na ₂ SO ₄ ·10H ₂ O
	gypsum	gypse	CaSO ₄ ·2H ₂ O
	epsomite arcanite	" "	MgSO ₄ ·7H ₂ O K ₂ SO ₄
Carbonates	calcite	"	CaCO ₃ (pH>7)
	natron	"	Na ₂ CO ₃ ·10H ₂ O (pH>7)
	thermonatrite	"	Na ₂ CO ₃ ·H ₂ O (pH>7)
	trona	"	Na ₃ H(CO ₃) ₂ ·2H ₂ O (pH>7)
Oxalates	weddellite	"	Ca(C ₂ O ₄)·2(H ₂ O)
	whewellite	"	Ca(C ₂ O ₄)·(H ₂ O)
Complex salts	ettringite	"	Ca ₃ Al ₂ (SO ₄) ₃ (OH) ₁₂ ·26H ₂ O
	darapskite	"	Na ₃ (SO ₄)(NO ₃)·H ₂ O

Stone materials and conservation of the built heritage – The soluble salts – BR 3



Origin of the soluble salts:

Natural origins:

- Sea water (all ions \neq NO_3^- , NH_4^+)
- Groundwaters (all ions)
- Fresh waters (all ions)
- Organic origin (NO_3^- , NH_4^+ , oxalates $\text{C}_2\text{O}_4^{2-}$, HC_2O_4^-)

Natural building materials:

→ ex. : sandstone of Berne (\approx 0.1% Ca^{2+} et SO_4^{2-})

Stone materials and conservation of the built heritage – The soluble salts – BR 4



Origin of the soluble salts:

Restoration materials:

- cleaning products (formic acid, ammonium carbonate)
- conservation products (oxalates)
- additives of the conservation products (ammonia)

Air pollution (sulphate, nitrogen oxides, etc.)

- dry deposition
- wet deposition

Stone materials and conservation of the built heritage – The soluble salts – BR 5



Origin of the soluble salts:

De-icing salts

- NaCl, CaCl_2 ,...

Alkali building materials

- Cement (Na^+ , K^+ , SO_4^{2-} ,...)
- Soluble glasses (Wasserglas) ($\text{K}^+ \pm \text{Na}^+ \pm \text{Li}^+$)
- Trass (Na^+ , K^+ , Mg^{2+} ,...)

Fireproof materials

- Boron salts
- Wasserglass

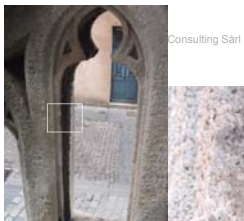
Stone materials and conservation of the built heritage – The soluble salts – BR 6

The crystallization problem

Stone materials and conservation of the built heritage – The soluble salts – BR 7

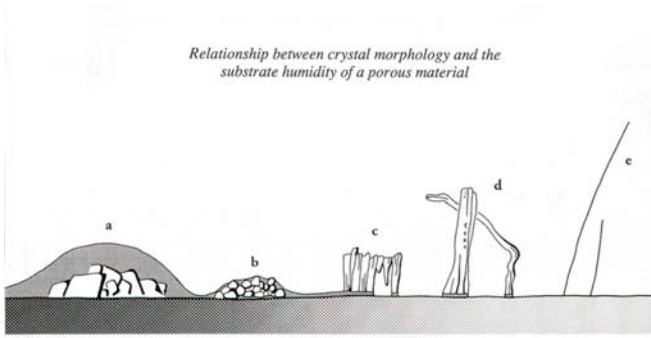


Stone materials and conservation of the built heritage – The soluble salts – BR 8



Nancy, 7.6.2008
Black crust of gypsum on the
Evville limestone

Stone materials and conservation of the built heritage – The soluble salts – BR 9



From: Arnold, A.; Zehnder, K. (1991): Monitoring wall paintings affected by soluble salts.- The Conservation of Wall Paintings. Proc. Symp. Courtauld Inst. Art & Getty Conservation Inst., London, July 13-16, 1987, 103-135.- The Getty Conservation Institute.

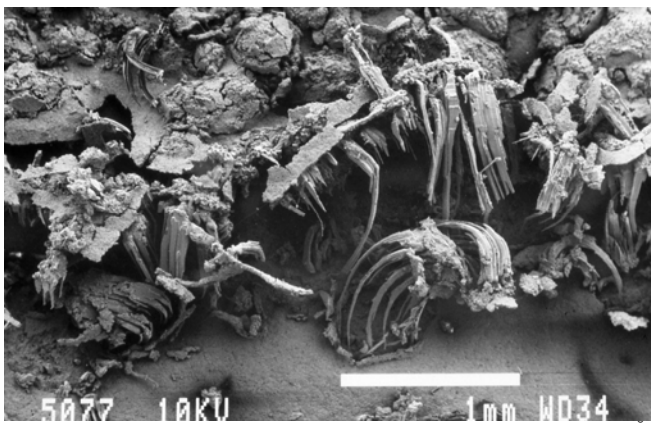
e soluble salts BR/10



Conservation Science Consulting Sàrl



Stone masonry and conservation of the built heritage - The soluble salts BR/11

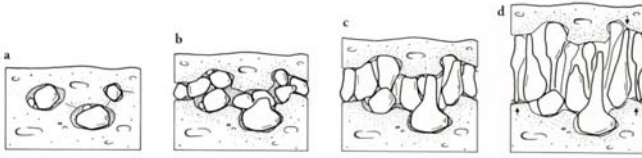


Paint layer on a ceramic with halite (NaCl) efflorescences (Laborexperiment)

Photo Konrad Zehnder

soluble salts BR/12

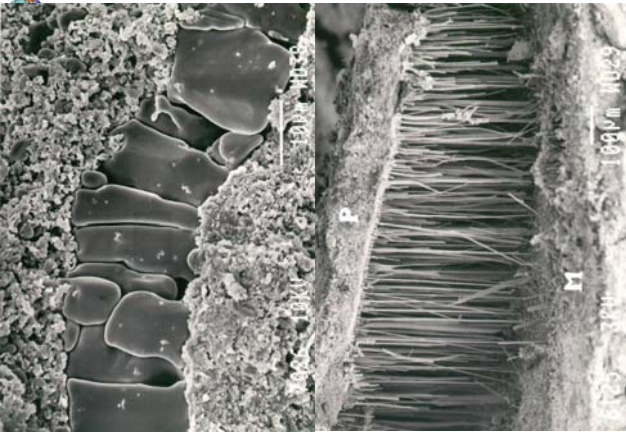
Model of disruption process by crystallizing salts



aus: Arnold, A.; Zehnder, K. (1991): Monitoring wall paintings affected by soluble salts.- The Conservation of Wall Paintings. Proc. Symp. Courtauld Inst. Art & Getty Conservation Inst., London, July 13-16, 1987, 103-135.- The Getty Conservation Institute.

Johns 8/98, BR /13

Photos: Konrad Zehnder

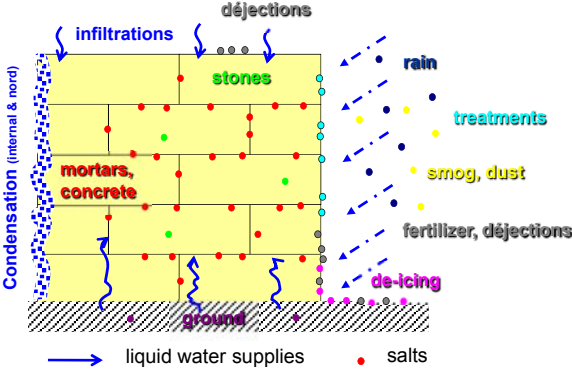


Nitronatrite (NaNO₂) in ceramic (lab. experiment)

Stone materials and conservation of the built heritage - The soluble salts, BR /14

Conservation Science Consulting Sàrl

Origin of salts and water in buildings

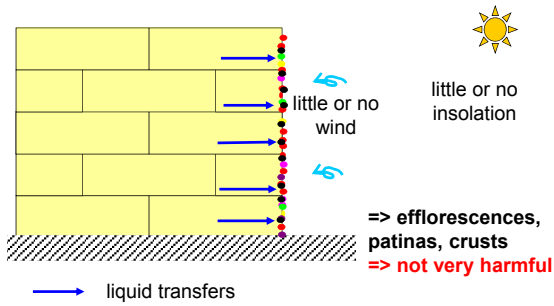


Stone materials and conservation of the built heritage - The soluble salts, BR /15

A series of horizontal lines for taking notes, corresponding to the images and text on the left.



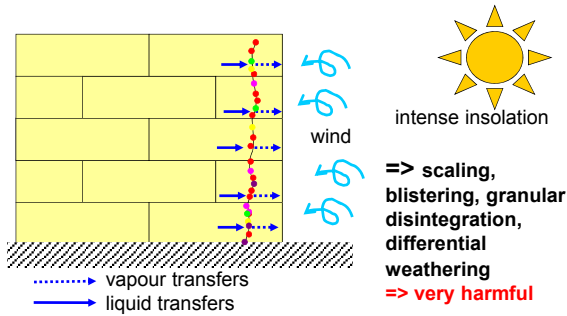
Evolution of water and salts in case of slow drying



Stone materials and conservation of the built heritage - The soluble salts - BR / 6



Evolution of water and salts in case of fast drying



Stone materials and conservation of the built heritage - The soluble salts - BR / 7



The hygroscopicity (or deliquescence) problem

Deliquescence humidity: the relative humidity above which a material absorbs humidity from the air and dissolves

Stone materials and conservation of the built heritage - The soluble salts - BR / 8



Fribourg, Notre-Dame basilica, 2.11.2008



Stone materials and composition of the built heritage – The soluble salts _ BR 1/9

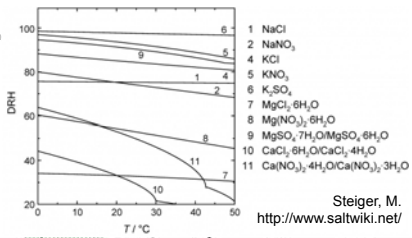


Kaysersberg castle, Alsace, France, 8.05.2008

© Vincent COURCELEAUD
(<http://www.trekearth.com/gallery/Europe/France/East/Alsace/Kaysersberg/photo909171.htm>)

Stone materials and composition of the built heritage – The soluble salts _ BR 2/0

Deliquescence humidity & temperature



Stone materials and composition of the built heritage – The soluble salts _ BR 2/1

Salt	0 °C	10 °C	20 °C	30 °C	40 °C	50 °C
NaCl	75.9	75.6	75.4	75.2	75.0	74.8
NaNO ₃	80.1	77.7	75.3	72.8	70.4	68.0
Na ₂ SO ₄	98.8 ⁽¹⁾	97.8 ⁽¹⁾	96.6 ⁽¹⁾	90.1 ⁽¹⁾	87.9	88.4
KCl	88.3	86.7	85.0	83.5	82.1	80.7
KNO ₃	97.0	95.5	93.7	91.5	88.9	85.9
MgCl ₂ ·6H ₂ O	34.1	33.7	33.1	32.4	31.5	30.5
Mg(NO ₃) ₂ ·6H ₂ O	61.3	58.6	55.7	52.5	49.2	45.7
MgSO ₄ ·7H ₂ O	94.5	93.1	91.3	89.1	86.3	83.2 ⁽²⁾
CaCl ₂ ·6H ₂ O	44.3	39.4	33.3	24.6 ⁽³⁾	18.4 ⁽³⁾	15.3 ⁽⁴⁾
Ca(NO ₃) ₂ ·4H ₂ O	63.8	58.8	53.1	46.0	35.5	21.3 ⁽⁵⁾

⁽¹⁾ Na₂SO₄-10H₂O, ⁽²⁾ MgSO₄-7H₂O, ⁽³⁾ CaCl₂-2H₂O, ⁽⁴⁾ CaCl₂-2H₂O, ⁽⁵⁾ Ca(NO₃)₂-4H₂O



Formula	Molecular mass	% H2O (w)	Name FR	Name EN	Solubility (g/l / 20°C)	Relative humidity of deliquescence or equilibrium (%)
CH3NH2	33.06		ammoniac	ammonia	1000	
CH3COOH	74.08		acide acétique	acetic acid	1000	
CH3COONa	82.07		acétate de sodium	sodium acetate	1000	
CH3COONH4	77.08		acétate d'ammonium	ammonium acetate	1000	
CH3COONH4.2H2O	121.10		acétate d'ammonium dihydraté	ammonium acetate dihydrate	1000	
CH3COONH4.3H2O	153.13		acétate d'ammonium trihydraté	ammonium acetate trihydrate	1000	
CH3COONH4.4H2O	185.16		acétate d'ammonium tétrahydraté	ammonium acetate tetrahydrate	1000	
CH3COONH4.5H2O	217.19		acétate d'ammonium pentahydraté	ammonium acetate pentahydrate	1000	
CH3COONH4.6H2O	249.22		acétate d'ammonium hexahydraté	ammonium acetate hexahydrate	1000	
CH3COONH4.7H2O	281.25		acétate d'ammonium heptahydraté	ammonium acetate heptahydrate	1000	
CH3COONH4.8H2O	313.28		acétate d'ammonium octahydraté	ammonium acetate octahydrate	1000	
CH3COONH4.9H2O	345.31		acétate d'ammonium nonahydraté	ammonium acetate nonahydrate	1000	
CH3COONH4.10H2O	377.34		acétate d'ammonium décahydraté	ammonium acetate decahydrate	1000	
CH3COONH4.11H2O	409.37		acétate d'ammonium undécahydraté	ammonium acetate undecahydrate	1000	
CH3COONH4.12H2O	441.40		acétate d'ammonium dodécahydraté	ammonium acetate dodecahydrate	1000	
CH3COONH4.13H2O	473.43		acétate d'ammonium trétrahydraté	ammonium acetate tetradecahydrate	1000	
CH3COONH4.14H2O	505.46		acétate d'ammonium pentadécahydraté	ammonium acetate pentadecahydrate	1000	
CH3COONH4.15H2O	537.49		acétate d'ammonium hexadécahydraté	ammonium acetate hexadecahydrate	1000	
CH3COONH4.16H2O	569.52		acétate d'ammonium heptadécahydraté	ammonium acetate heptadecahydrate	1000	
CH3COONH4.17H2O	601.55		acétate d'ammonium octadécahydraté	ammonium acetate octadecahydrate	1000	
CH3COONH4.18H2O	633.58		acétate d'ammonium nonadécahydraté	ammonium acetate nonadecahydrate	1000	
CH3COONH4.19H2O	665.61		acétate d'ammonium eicosahydraté	ammonium acetate icosahydrate	1000	
CH3COONH4.20H2O	697.64		acétate d'ammonium hénécahydraté	ammonium acetate heneicosahydrate	1000	
CH3COONH4.21H2O	729.67		acétate d'ammonium triacosahydraté	ammonium acetate triacosahydrate	1000	
CH3COONH4.22H2O	761.70		acétate d'ammonium tetracosahydraté	ammonium acetate tetracosahydrate	1000	
CH3COONH4.23H2O	793.73		acétate d'ammonium pentacosahydraté	ammonium acetate pentacosahydrate	1000	
CH3COONH4.24H2O	825.76		acétate d'ammonium hexacosahydraté	ammonium acetate hexacosahydrate	1000	
CH3COONH4.25H2O	857.79		acétate d'ammonium heptacosahydraté	ammonium acetate heptacosahydrate	1000	
CH3COONH4.26H2O	889.82		acétate d'ammonium octacosahydraté	ammonium acetate octacosahydrate	1000	
CH3COONH4.27H2O	921.85		acétate d'ammonium nonacosahydraté	ammonium acetate nonacosahydrate	1000	
CH3COONH4.28H2O	953.88		acétate d'ammonium triatriacontahydraté	ammonium acetate triatriacontahydrate	1000	
CH3COONH4.29H2O	985.91		acétate d'ammonium tétraatriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.30H2O	1017.94		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.31H2O	1049.97		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.32H2O	1082.00		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.33H2O	1114.03		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.34H2O	1146.06		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.35H2O	1178.09		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.36H2O	1210.12		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.37H2O	1242.15		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.38H2O	1274.18		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.39H2O	1306.21		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.40H2O	1338.24		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.41H2O	1370.27		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.42H2O	1402.30		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.43H2O	1434.33		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.44H2O	1466.36		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.45H2O	1498.39		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.46H2O	1530.42		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.47H2O	1562.45		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.48H2O	1594.48		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.49H2O	1626.51		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.50H2O	1658.54		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.51H2O	1690.57		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.52H2O	1722.60		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.53H2O	1754.63		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.54H2O	1786.66		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.55H2O	1818.69		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.56H2O	1850.72		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.57H2O	1882.75		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.58H2O	1914.78		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.59H2O	1946.81		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.60H2O	1978.84		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.61H2O	2010.87		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.62H2O	2042.90		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.63H2O	2074.93		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.64H2O	2106.96		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.65H2O	2138.99		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.66H2O	2171.02		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.67H2O	2203.05		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.68H2O	2235.08		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.69H2O	2267.11		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.70H2O	2299.14		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.71H2O	2331.17		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.72H2O	2363.20		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.73H2O	2395.23		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.74H2O	2427.26		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.75H2O	2459.29		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.76H2O	2491.32		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.77H2O	2523.35		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.78H2O	2555.38		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.79H2O	2587.41		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.80H2O	2619.44		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.81H2O	2651.47		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.82H2O	2683.50		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.83H2O	2715.53		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.84H2O	2747.56		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.85H2O	2779.59		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.86H2O	2811.62		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.87H2O	2843.65		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.88H2O	2875.68		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.89H2O	2907.71		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.90H2O	2939.74		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.91H2O	2971.77		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.92H2O	3003.80		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.93H2O	3035.83		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.94H2O	3067.86		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	
CH3COONH4.95H2O	3099.89		acétate d'ammonium tétratriacontahydraté	ammonium acetate tetraatriacontahydrate	1000	
CH3COONH4.96H2O	3131.92		acétate d'ammonium pentatriacontahydraté	ammonium acetate pentatriacontahydrate	1000	
CH3COONH4.97H2O	3163.95		acétate d'ammonium hexatriacontahydraté	ammonium acetate hexatriacontahydrate	1000	
CH3COONH4.98H2O	3195.98		acétate d'ammonium heptatriacontahydraté	ammonium acetate heptatriacontahydrate	1000	
CH3COONH4.99H2O	3228.01		acétate d'ammonium octatriacontahydraté	ammonium acetate octatriacontahydrate	1000	
CH3COONH4.100H2O	3260.04		acétate d'ammonium nonatriacontahydraté	ammonium acetate nonatriacontahydrate	1000	