

# Memory of shape

Nanotechnology 2019



# Memory metal

- Nitinol – an alloy of Ni and Ti discovered in 1959.
- Property of “remembering” a shape in which it is *annealed*
- (annealing is the process of heating a piece of metal to a high temperature then cooling rapidly in water)

Periodic Table of the Elements

1 H Hydrogen 1.01																	2 He Helium 4.00															
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18															
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95															
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 84.80															
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.29															
55 Cs Cesium 132.91	56 Ba Barium 137.33	Lanthanides		72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (209)	86 Rn Radon 222.02														
67 Fr Francium 223.02	68 Ra Radium 226.03	Actinides		104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)														
57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97				89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium (254)	100 Fm Fermium 257.10	101 Md Mendelevium 258.10	102 No Nobelium 259.10	103 Lr Lawrencium (262)

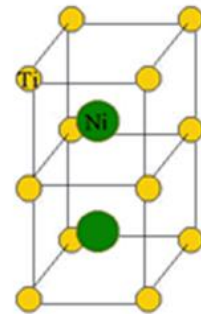
Legend:

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Metalloid
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

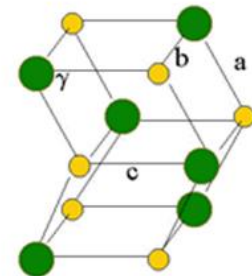
# How does Nitinol work?

- Nitinol exists in two forms which are stable at different temperatures
- **Austenite** = high temperature
- **Martensite** = low temperature

Austenite



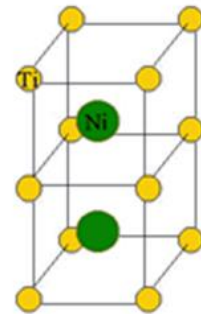
Martensite



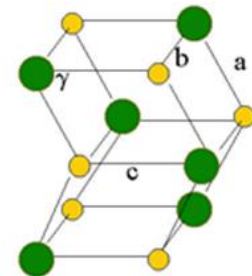
# How does Nitinol work?

- Austenite and martensite have different structures
- **Austenite:** body-centred-cube
- **Martensite:** monoclinic twin

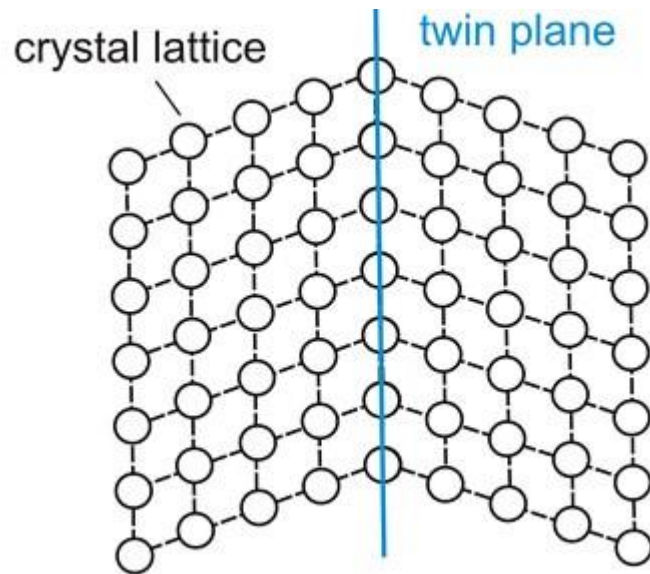
Austenite



Martensite



# Twinning in crystals



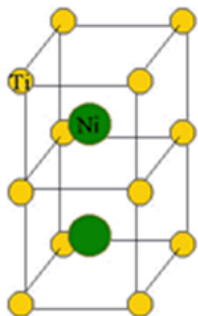
Twinned selenite

# How does Nitinol work?

- Martensite is flexible because the crystal planes of the twinned form can slide across each other to give a detwinned form.
- This allows the crystal to be deformed like an accordion

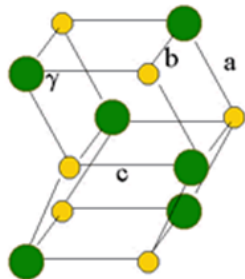


Austenite

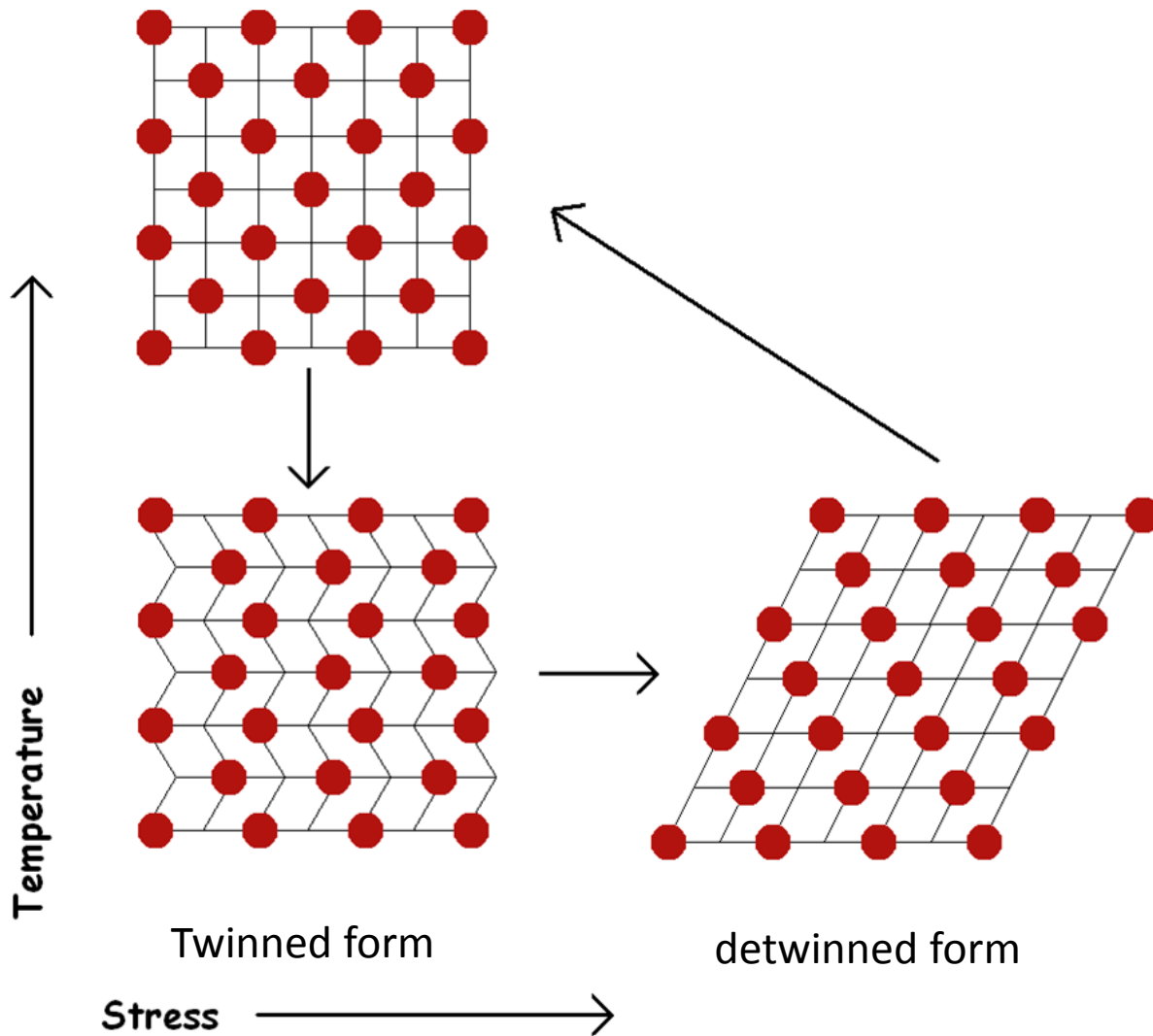


Body centred cubic

Martensite

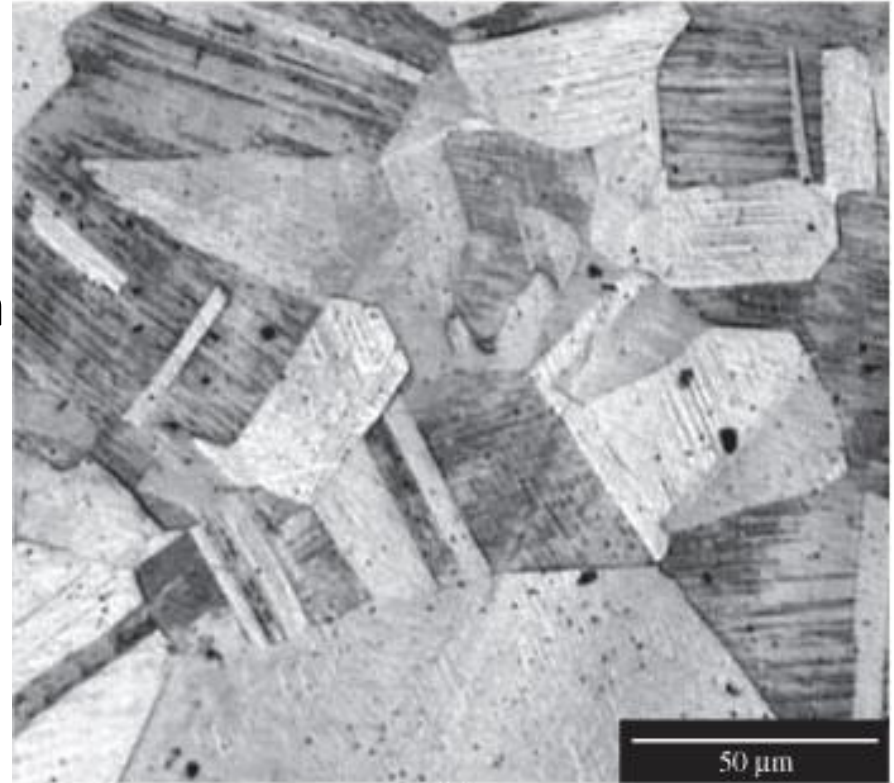


Monoclinic twinned



# Solid-solid phase transition

- Upon heating, the nitinol returns to its annealed form (austenite)
- The transition from one form to the other does NOT occur at a single temperature.
- Domains of martensite and austenite mix within the structure as it converts



(b)

**Figure 1.** Optical microscopy: a) grain boundary of austenitic matrix,  $GS = 106 \mu\text{m}$ . Etchant:  $2\text{mlHNO}_3 + 2\text{mlNH}_4\text{Cl}$ , and b) stress induced  $\epsilon_{\text{acc}}$  - martensite (dark region) and  $\gamma_{\text{acc}}$  - austenite (bright region), 6<sup>th</sup> thermo-mechanical cycle,  $GS = 75 \mu\text{m}$ . Color Etching:  $\text{K}_2\text{S}_2\text{O}_8 + \text{NH}_2\text{HF}_2$  in distilled water<sup>19</sup>.



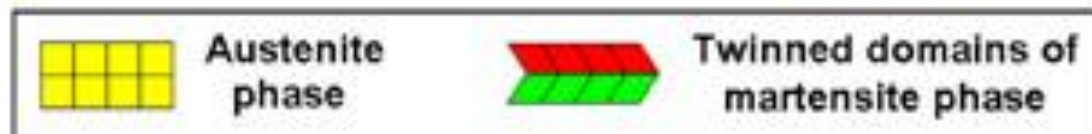
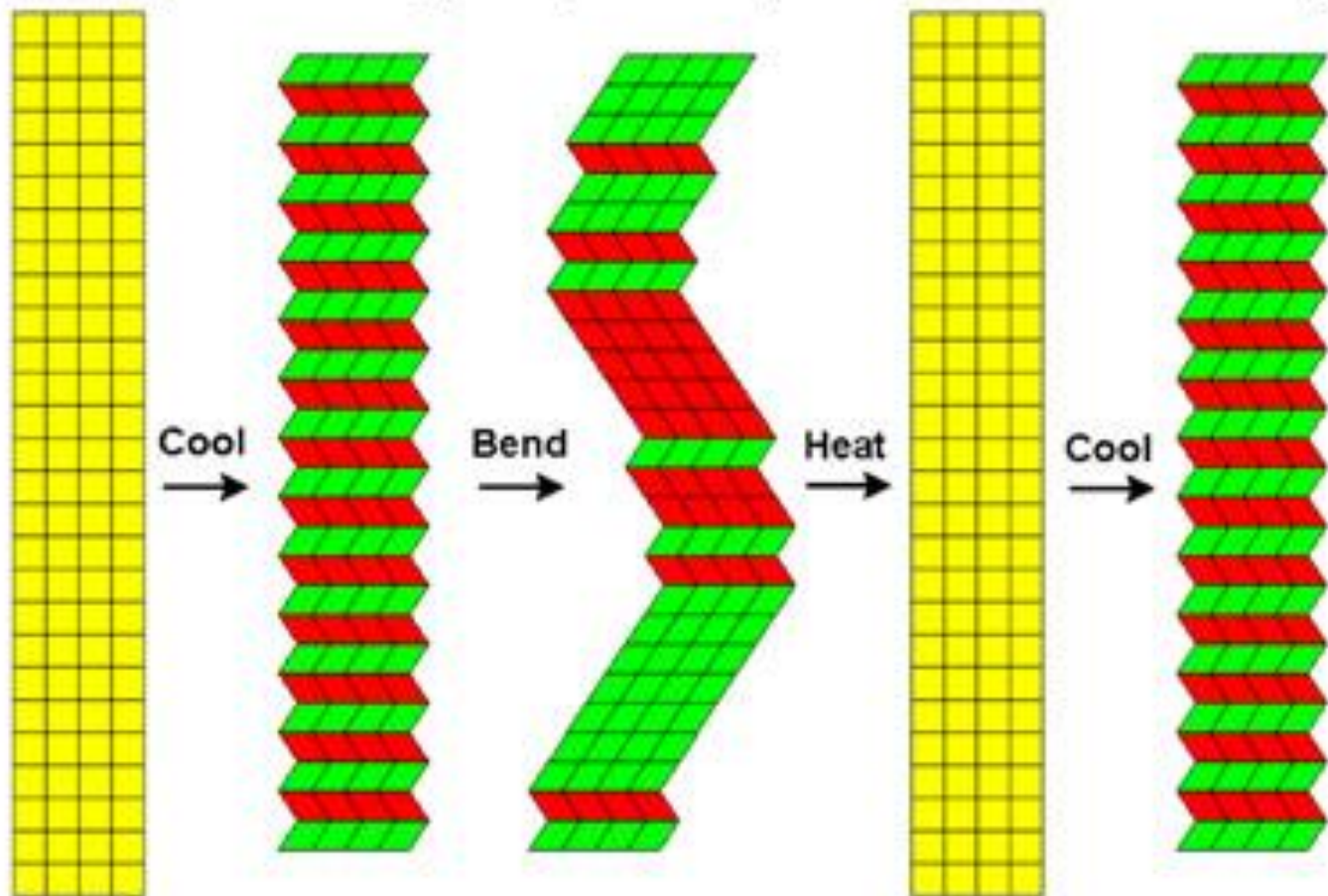
**a** Define shape at **high temperature** (austenite)

**b** Cool to **low temperature** (martensitic twinning)

**c** Mechanically deform at **low temperature** (martensite)

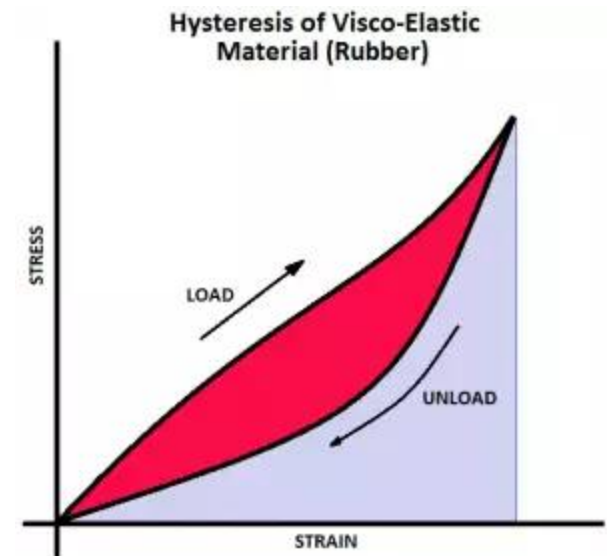
**d** Heat to **high temperature** (austenite)

**e** Cool to **low temperature** (martensitic twinning)

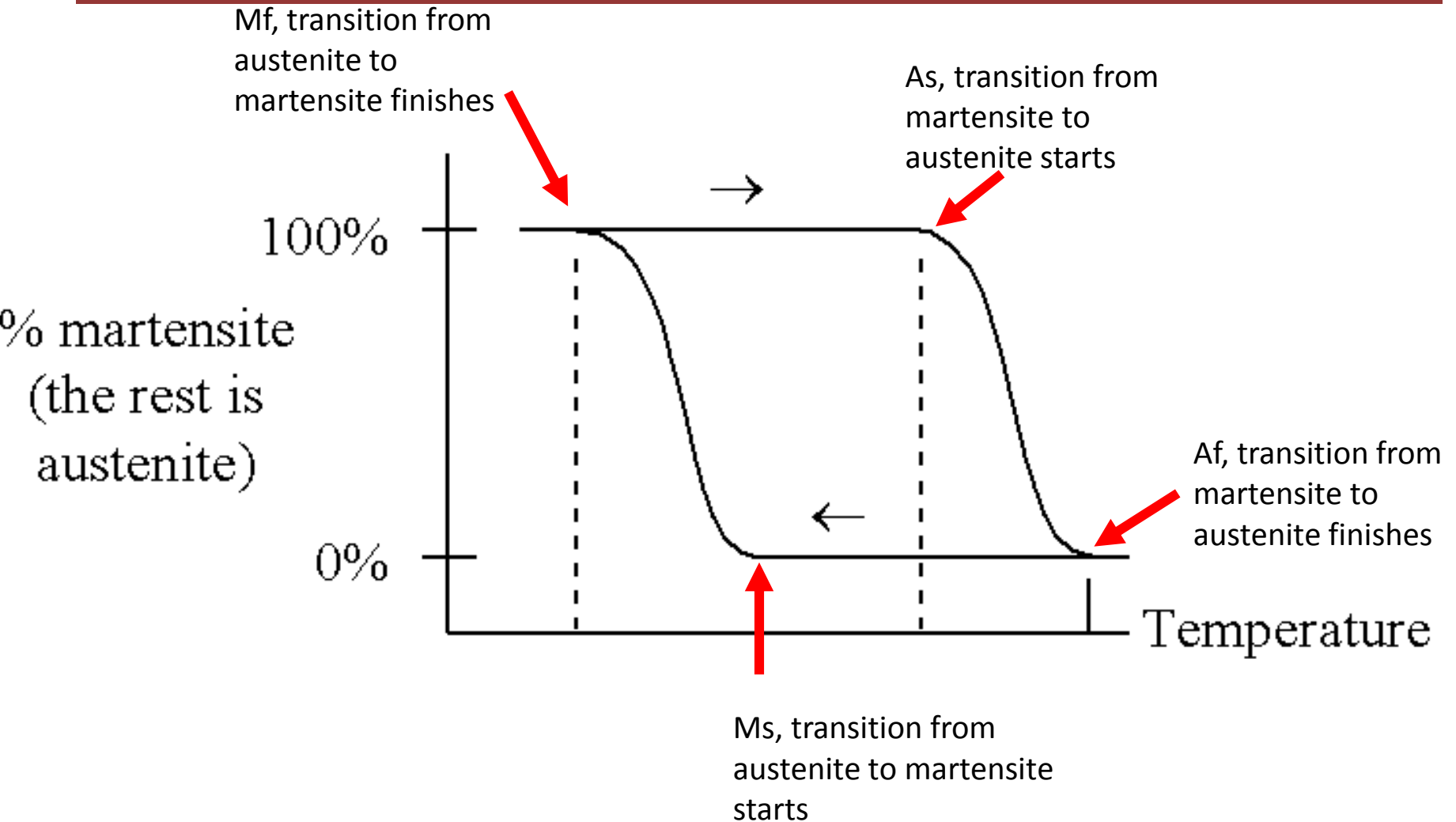


# Hysteresis

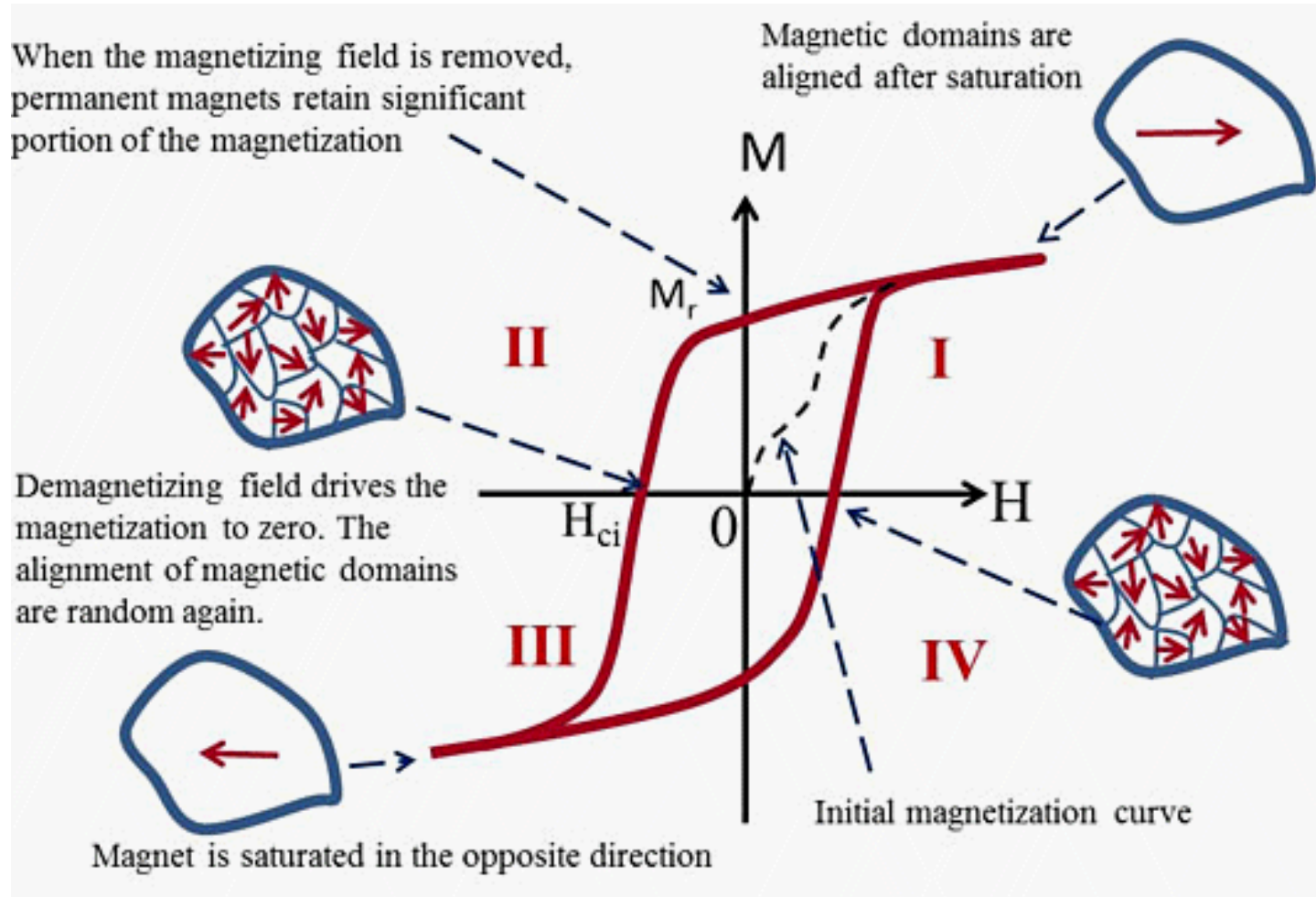
- The heating and cooling curves *do not superimpose upon each other*
- This is described as hysteresis which is also encountered in magnetism
- It is caused because the metal *is not a homogeneous structure*: it is composed of domains which are of one form or the other.
- The domains require time and energy to interconvert.



# Hysteresis in memory metal

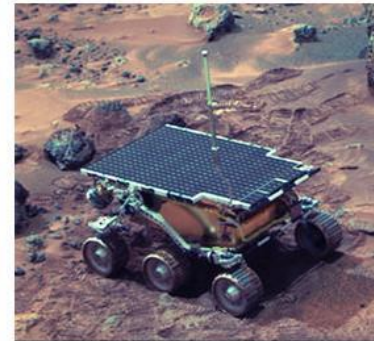


# Magnetic Hysteresis



Magnetisation vs magnetic field (external)

# Uses of nitinol



## **Flexinol on Mars**

Flexinol operated a dust sensor on the Sojourner rover which landed on Mars July 4, 1997.

