A

Units in Magnetism

The International System of Units (Système International d'Unités) (SI) contains two types of units: base units and derived units. The seven base units are: meter, kilogram, second, ampere, kelvin, mole, and candela.

Some units relevant to magnetism have special names in the SI. They are the following, together with their expression in terms of other SI units:

Table A.1. Table of magnetic units in the SI

Unit	Symbol	Equivalence	Quantity
weber	Wb	V s	Unit of magnetic flux
henry	H	Wb A^{-1}	Unit of inductance
tesla	T	Wb m^{-2}	Unit of magnetic flux density

The unit of magnetic field strength **H** has no special name; **H** is measured in amperes per meter (A m^{-1}).

The magnetic induction or magnetic flux density **B** (or simply B-field) has the tesla (T) as the unit and is related to the magnetic field intensity **H** through the magnetic constant or vacuum magnetic permeability μ_0, that has a value of $4\pi \times 10^{-7}$ H m^{-1} in the SI.

The relations between **B** and **H** in the two systems of units are:

$$\begin{aligned} \mathbf{B} &= \mu_0(\mathbf{H}+\mathbf{M}) \qquad \text{(SI)} \\ \mathbf{B} &= \mathbf{H}+4\pi\mathbf{M} \qquad \text{(CGS)} \end{aligned} \tag{A.1}$$

In the last equation (in the centimeter-gram-second system (CGS)) **B** is measured in gauss (G) and the unit of **H** is the oersted (Oe). In the CGS system the constant 4π appears explicitly in the expression of **B**.

The magnetization **M** of a sample, defined as the total magnetic moment divided by the volume, is measured in A m^{-1}. A close concept is that of polarization $\mathbf{J} = \mu_0 \mathbf{M}$, measured in teslas (T).

The literature of magnetism contains results both in SI and CGS units. Some useful relations for conversion of CGS into the SI are:

$$
\begin{aligned}
1\,\mathrm{G} &= \quad 10^{-4}\,\mathrm{T} \\
1\,\mathrm{Oe} &= \tfrac{10^3}{4\pi}\,\mathrm{A\,m^{-1}} \quad \approx 80\,\mathrm{A\,m^{-1}} \\
1\,\mathrm{emu\,g^{-1}} &= 1\,\mathrm{J\,T^{-1}kg^{-1}}
\end{aligned}
\tag{A.2}
$$

Note that “emu” is not the name of a unit, it designates 1 erg gauss^{-1}.

The relative magnetic permeability μ_r of a material is dimensionless, and is defined as the ratio of the permeability of the material μ to the magnetic constant (or free-space permeability) μ_0:

$$\mu_r = \frac{\mu}{\mu_0}. \tag{A.3}$$

The relative permeability of a material μ_r is measured by the same number in the SI and in the CGS. Its relation to the susceptibility $\chi = M/H$, however, is different in the two systems:

$$
\begin{aligned}
\mu_r &= 1 + \chi \qquad \text{(SI)} \\
\mu_\mathrm{r} &= 1 + 4\pi\chi \qquad \text{(CGS)}
\end{aligned}
\tag{A.4}
$$

The expressions differ because the values of the susceptibilities are different in the two systems:

$$\chi_{\mathrm{SI}} = 4\pi\, \chi_{\mathrm{CGS}}. \tag{A.5}$$

Further Reading

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Magnetic quantities and units. To obtain the values of the quantities in SI units, the corresponding CGS values should be multiplied by the conversion factors

Quantity	Symbol	CGS	SI	Conversion factor
Magnetic induction	$\mathbf{B}$	G	T	10^{-4}
Magnetic field intensity	$\mathbf{H}$	Oe	$\mathrm{A\,m^{-1}}$	$10^3/4\pi$
Magnetization	$\mathbf{M}$	$\mathrm{erg\,G^{-1}\,cm^{-3}}$ or $\mathrm{emu\,cm^{-3}}$	$\mathrm{A\,m^{-1}}$	10^3
Magnetic polarization	$\mathbf{J}$	–	T	–
Magnetic moment	m	$\mathrm{erg\,G^{-1}}$ ($\equiv$ emu)	$\mathrm{J\,T^{-1}}$ ($\equiv \mathrm{A\,m^2}$)	10^{-3}
Specific magnetization	σ	$\mathrm{emu\,g^{-1}}$	$\mathrm{A\,m^2\,kg^{-1}(J\,T^{-1}\,kg^{-1})}$	1
Magnetic flux	ϕ	Mx (Maxwell)	Wb (Weber)	10^{-8}
Magnetic energy density	E	$\mathrm{erg\,cm^{-3}}$	$\mathrm{J\,m^{-3}}$	10^{-1}
Demagnetizing factor	$\mathrm{N_d}$	–	–	$1/4\pi$
Susceptibility (volume)	χ	–	–	4π
Mass susceptibility	χ_g	$\mathrm{erg\,G^{-1}\,g^{-1}\,Oe^{-1}}$ or $\mathrm{emu\,g^{-1}\,Oe^{-1}}$	$\mathrm{m^3\,kg^{-1}}$	$4\pi \times 10^{-3}$
Molar susceptibility	χ_{mol}	$\mathrm{emu\,mol^{-1}Oe^{-1}}$	$\mathrm{m^3mol^{-1}}$	$4\pi \times 10^{-6}\ \mathrm{m^3mol^{-1}}$
Magnetic permeability	μ	$\mathrm{G\,Oe^{-1}}$	$\mathrm{H\,m^{-1}}$	$4\pi \times 10^{-7}$
Relative permeability	μ_r	–	–	1
Magnetic constant (vacuum permeability)	μ_0	$\mathrm{G\,Oe^{-1}}$	$\mathrm{H\,m^{-1}}$	$4\pi \times 10^{-7}$
Anisotropy constant	K	$\mathrm{erg\,cm^{-3}}$	$\mathrm{J\,m^{-3}}$	10^{-1}
Exchange stiffness constant	A	$\mathrm{erg\,cm^{-1}}$	$\mathrm{J\,m^{-1}}$	10^5
Specific domain wall energy	γ	$\mathrm{erg\,cm^{-2}}$	$\mathrm{J\,m^{-2}}$	10^{-3}
Gyromagnetic ratio	γ	$\mathrm{s^{-1}\,Oe^{-1}}$	$\mathrm{m\,A^{-1}\,s^{-1}}$	$4\pi 10^{-3}$

B

Physical Constants

Quantity	Symbol	Value	CGS	SI
Speed of light in vacuum	c	2.997925	10^{10} cm s^{-1}	10^{8} m s^{-1}
Elementary charge	e	1.60218	4.80654×10^{-10} statC	10^{-19}C
Planck constant	h	6.62607	10^{-27} erg s	10^{-34} J s
	$\hbar = h/2\pi$	1.054572	10^{-27} erg s	10^{-34} J s
Avogadro's constant	N_A	6.02214 $\times10^{23}$ mol^{-1}		
Atomic mass constant	m_u	1.66054	10^{-24} g	10^{-27} kg
Electron mass	m_e	9.10939	10^{-28} g	10^{-31} kg
Proton mass	m_p	1.67262	10^{-24} g	10^{-27} kg
Ratio of proton and electron masses	m_p/m_e	1836.153		
Electron gyromagnetic ratio	γ_e	1.760859770	10^{7} s^{-1} G^{-1}	10^{11} s^{-1} T^{-1}
Gilbert gyromagnetic ratio	$\mu_0\gamma_e$	2.2127606		10^{5} m A^{-1}s^{-1}
Electron Compton wavelength	λ_c	2.42631	10^{-10} cm	10^{-12} m
Bohr radius	a_0	0.529177	10^{-8} cm	10^{-10} m
Bohr magneton	μ_B	9.2740154	10^{-21} erg G^{-1}	10^{-24} JT^{-1}
Nuclear magneton	μ_N	5.0507866	10^{-24} erg G^{-1}	10^{-27} JT^{-1}
Electronvolt	eV	1.60218	10^{-12} erg	10^{-19} J
Boltzmann constant	k	1.380658	10^{-16} erg K^{-1}	10^{-23} JK^{-1}
Reciprocal of fine structure constant	$1/\alpha$	137.036		
Rydberg constant	$R_\infty hc$	2.179874	10^{-11} erg	10^{-18} J
Molar gas constant	R	8.31451	10^{7} erg mol^{-1} K^{-1}	J mol^{-1} K^{-1}
Vacuum permittivity	ε_0	–	1	$10^{7}/4\pi c^{2}$
Magnetic constant (vacuum permeability)	μ_0		1	$4\pi\times10^{-7}$ Hm^{-1}

Materials

Symbols

A exchange stiffness constant, 5
a lattice parameter, 43
α angle of the AFM magnetization, 120
α aspect ratio, 32
α damping constant, 40
α two-domain E_{ms} reduction factor, 49
α volume geometric factor, 82
α_{d} co-factor of dipolar sum, 100
α_{F} spin asymmetry parameter, 132
$\alpha_{\mathrm{F/N}}$ spin asymmetry parameter, 139
α_{G} Gilbert damping constant, 40
α_i direction cosines, 34

B distance between recorded transitions, 175
B magnetoelastic coupling constant, 34
$\mathbf{B}$ magnetic induction, 22
β angle between μ and H, 102
β angle of the FM magnetization, 120
β non-adiabaticity parameter, 168
β_{F} spin asymmetry parameter, 138
$B_J(x)$ Brillouin function, 25
B_{m} molecular field, 25
B_{me} magnetoelastic coupling coefficient, 113

C Curie constant, 25
c vortex circulation, 151
C^* exchange field intensity parameter, 102
χ magnetic susceptibility, 22
χ_P Pauli susceptibility, 12

D particle size, 54
D stiffness constant, 4
d interparticle distance, 100
D_0 characteristic length, 58
D_0 single-domain critical diameter, 62
D_1 critical diameter for vortex state, 67
D_2 critical single-domain diameter for hard magnet, 67
D_{cr} critical single-domain diameter, 5
d_{cr} critical thickness, 114
$D_{\mathrm{cr}}^{\mathrm{inh}}$ D_{cr} for inhomogeneous nucleation, 91
$D_{\mathrm{cr}}^{\mathrm{ring}}$ ring critical diameter for vortex, 157
$D_{\mathrm{cr}}^{\mathrm{vo}}$ vortex critical diameter, 150
$D(E)$ density of states, 6
d_{e} equilibrium interplanar spacing, 107
Δ domain wall width parameter, 5
δ_0 domain wall width, 5
$\Delta d(12)$ variation of interplanar spacing, 107
δ_s out of equilibrium spin density, 132
Δt magnetization reversal time, 94

e electron charge, 96
E_0 energy of the $n = 1$ level, 8
E_{A} anisotropy energy, 32
E_{B} energy barrier height, 59
$\overline{E_{\mathrm{B}}}$ average barrier energy, 73
E_{ex} exchange energy, 29
E_{ext} energy in external field, 35
E_{F} Fermi energy, 8
E_{me} magnetoelastic energy, 34
E_{ms} magnetostatic energy, 30
ε strain, 33
ε_{d} dipolar energy, 100
η efficiency of write head, 176
η field sweep rate, 115

g g-factor, 25
g spin transfer function, 96
g write head gap width, 176
γ domain wall energy, 6
γ gyromagnetic ratio (Landau), 40
γ spin asymmetry parameter, 138
γ surface energy, 106
γ_e electron gyromagnetic ratio, 40
γ_{G} Gilbert gyromagnetic ratio, 40

H separation between tracks, 175
$\mathbf{H}$ magnetic field intensity, 22
h reduced magnetic field, 87
H_{c}^* dynamic coercivity, 115
H_0 deep gap field, 176
H_{A} anisotropy field, 36
H_{c} coercive field, 27
H_{c} magnetic field at the head core, 176
H_{c}^i intrinsic coercivity, 93
H_{cr}^{vo} critical vortex field, 153
H_{d} demagnetizing field, 41
$\mathbf{H}_{\mathrm{d}}$ demagnetizing field, 30
H_{dp} depinning field, 115
$\mathbf{H}_{\mathrm{eff}}$ effective field, 36
H_{g} magnetic field at the gap, 176
H_{max} maximum field, 27
H_{N} nucleation field, 63

H_p peak field, 52
H_{sat} saturation field, 98
H_{sw} switching field, 63
H_t total magnetic field, 102

i current, 96

J total angular momentum, 23
$\mathscr{J}$ exchange integral, 29
$\mathbf{J}$ magnetic polarization, 22
j current density, 132
J_1 interlayer exchange coupling constant, 122
J_c critical current density, 169
$j_\downarrow$ spin down current density, 132
J_{int} interface coupling constant, 120
j_s spin current density, 132
$j_\uparrow$ spin up current density, 132

K anisotropy constant, 5, 33
k wavevector, 4
K_1 first anisotropy constant, 33
K_2 second anisotropy constant, 33
$\langle K \rangle$ average anisotropy, 54
κ hardness parameter, 37
κ imaginary wave vector, 146
k_B Boltzmann constant, 4
K_d shape anisotropy energy, 85
K_{eff} effective anisotropy constant, 34
k_F Fermi wavevector, 8
K_s surface anisotropy constant, 76
K_{vol} macroscopic anisotropy constant, 77

ℓ core length, 176
λ magnetostriction, 34
λ shift exponent, 19, 162
λ_F Fermi wavelength, 10
λ_m molecular field constant, 25
λ_{m} molecular field parameter, 17
λ_{mfp} electron mean free path, 128
λ_s saturation magnetostriction, 34
l_{ex} exchange length, 5
l_{sd} spin diffusion length, 128
$L(x)$ Langevin function, 75

$\mathbf{M}$ magnetization, 22
m electron mass, 7
m reduced magnetization, 29
M_0 magnetization at $T = 0$ K, 25
$M_d(H)$ DC remanence, 98
MR magnetoresistance, 127
M_r retentivity, remanence, 27
$M_r(H)$ isothermal remanence, 98
M_s saturation magnetization, 5
m_{inf} lower branch of magnetization, 98
m_{sup} upper branch of magnetization, 98
μ chemical potential, 132
μ domain wall mobility, 52
μ magnetic permeability, 22
μ particle magnetic moment, 100
μ_0 magnetic constant or vacuum permeability, 5
μ_0 spin averaged chemical potential, 133
μ_B Bohr magneton, 25
μ_J atomic magnetic moment, 25
μ_r relative permeability, 23
μ_s out of equilibrium chemical potential, 133
μ_s spin accumulation, 133
μ_{s} spin magnetic moment, 26
μ^z z component of the magnetic moment, 75
m_{vir} virgin magnetization, 98

N number of electron collisions, 128
N number of occupied electron states, 8
n electron density, 12
n number of ions per unit volume, 25
n quantum number, 8
n winding number, 155
N_a demagnetizing factor, a axis, 93
N_c demagnetizing factor, c axis, 93
N_d demagnetizing factor, 31
N_{eff} effective demagnetizing factor, 36
NN number of nearest neighbors, 108
$N_\parallel$ parallel demagneting factor, 36
$N_\perp$ perpendicular demagnetizing factor, 36
ν frequency of jumps, 68

p dimensionality, 9
p vortex polarity, 151
P_j electron current polarization, 132
$P(t)$ probability of particle not inverting after t, 71

Q quality parameter, 37
q skyrmion number, 155

R_0 resistance without applied field, 127
R_{AP} resistance, antiparallel, 134
R_c vortex core radius, 151

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