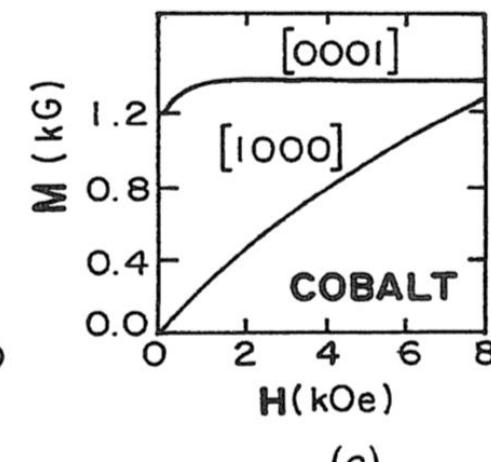
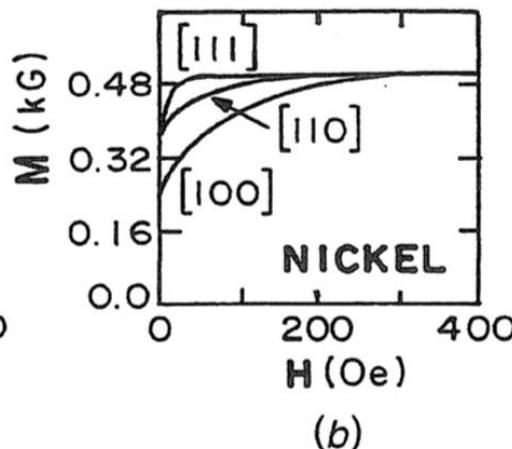
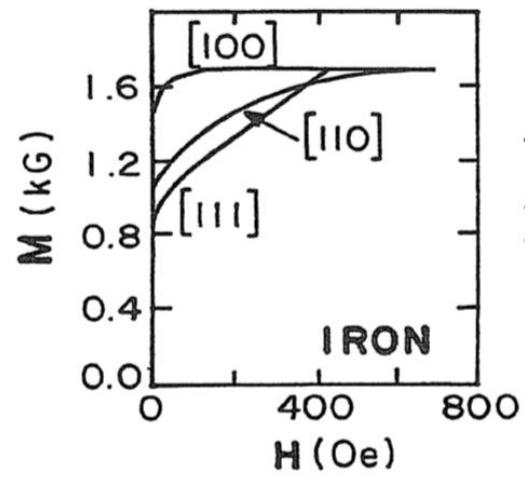
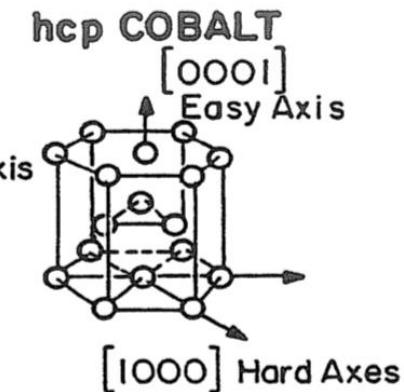
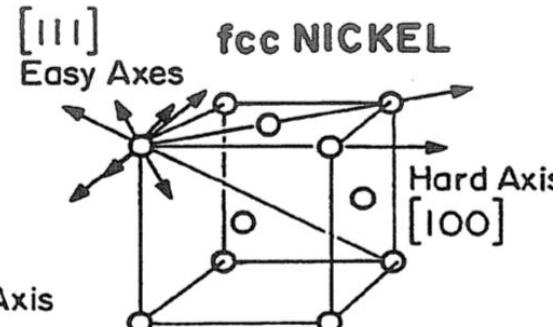
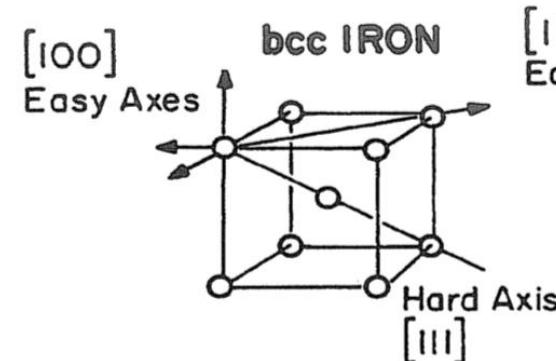


# A Simple Introduction to Magnetic Anisotropy

Detian Yang

07/05/2019

# Magnetic Anisotropy: OBSERVATIONS

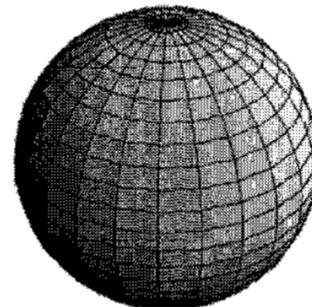


# Phenomenology of Magnetic Anisotropy

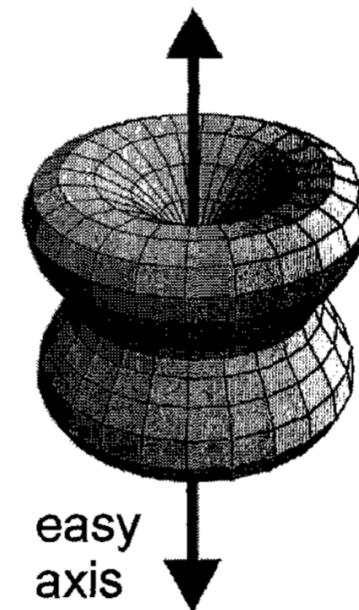
- How to characterize MA?

$$u_a = \frac{U_0}{V_0} = u_a(\theta, \phi), \text{ T fixed}$$

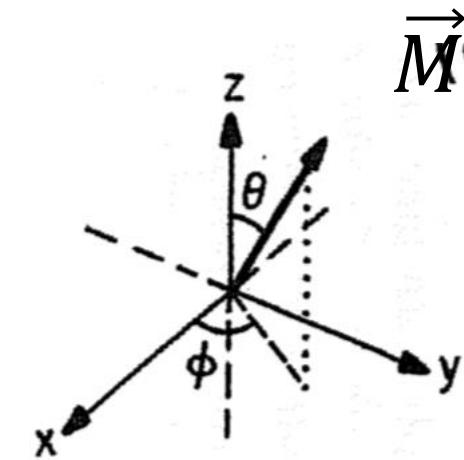
Free Energy Surface



exchange  
only

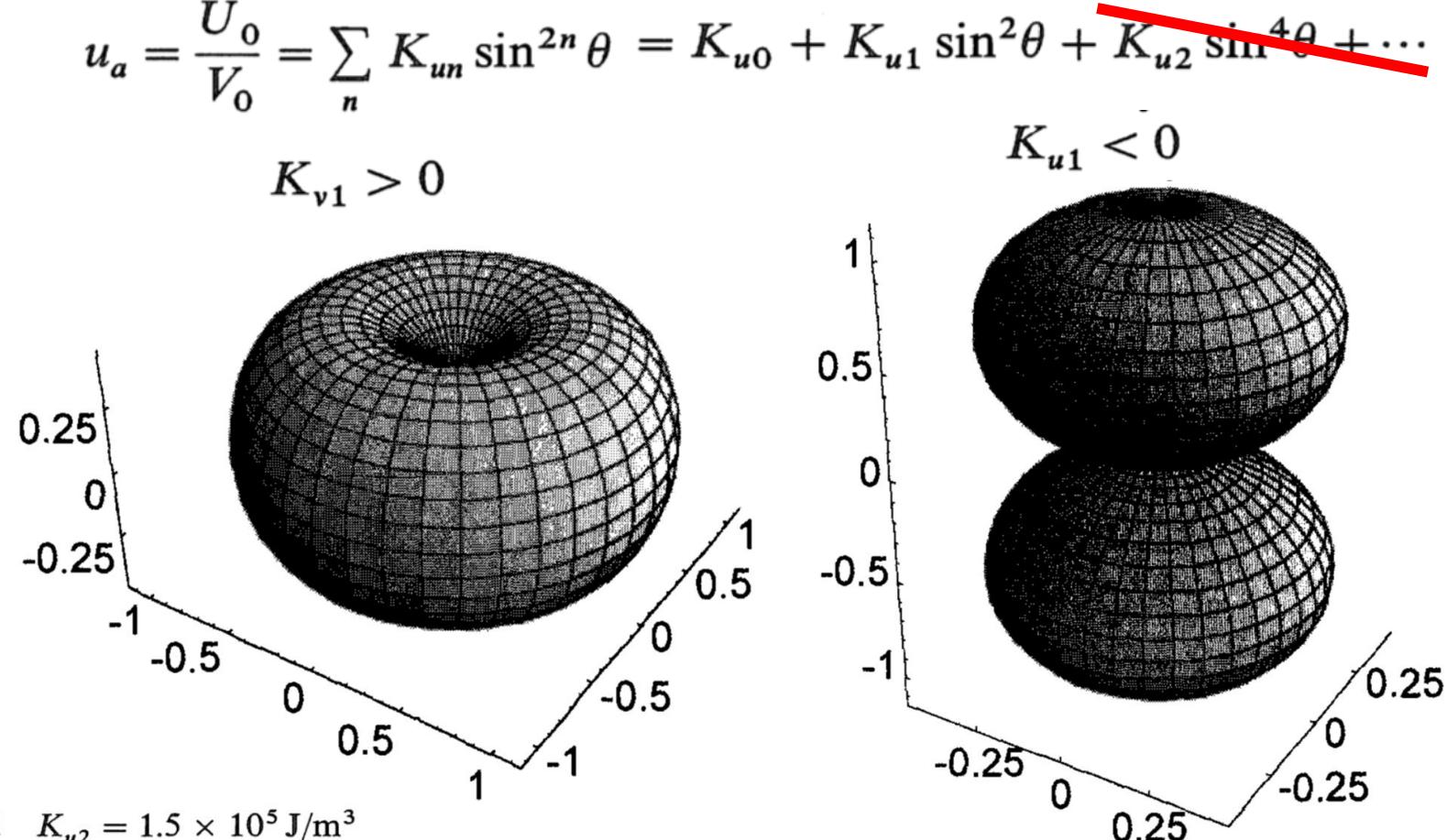
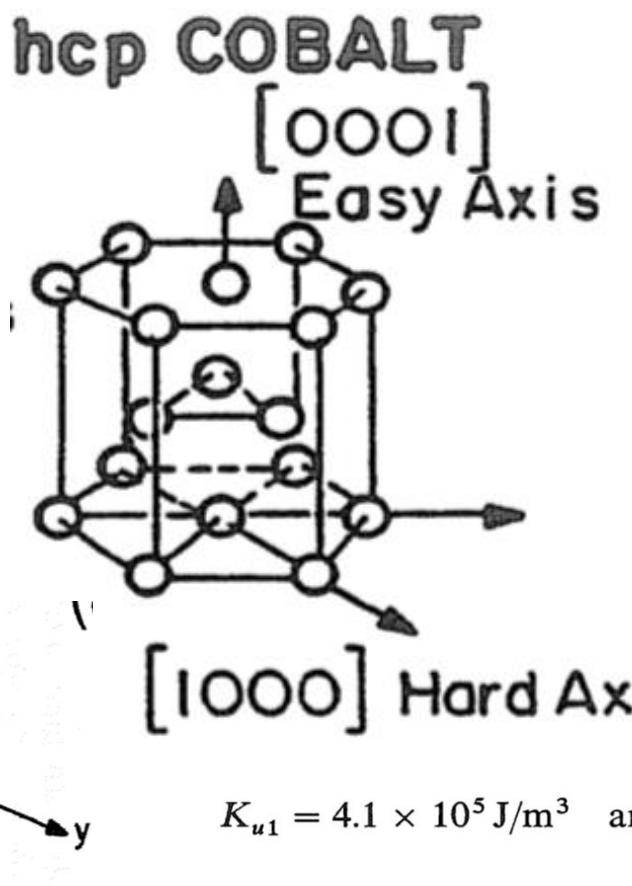


easy  
axis

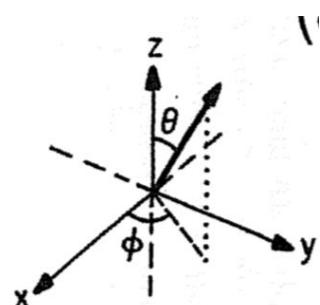
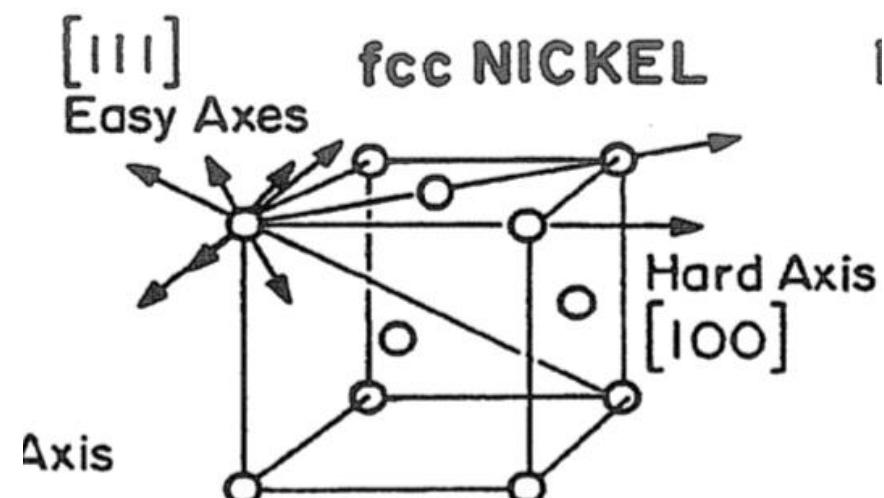
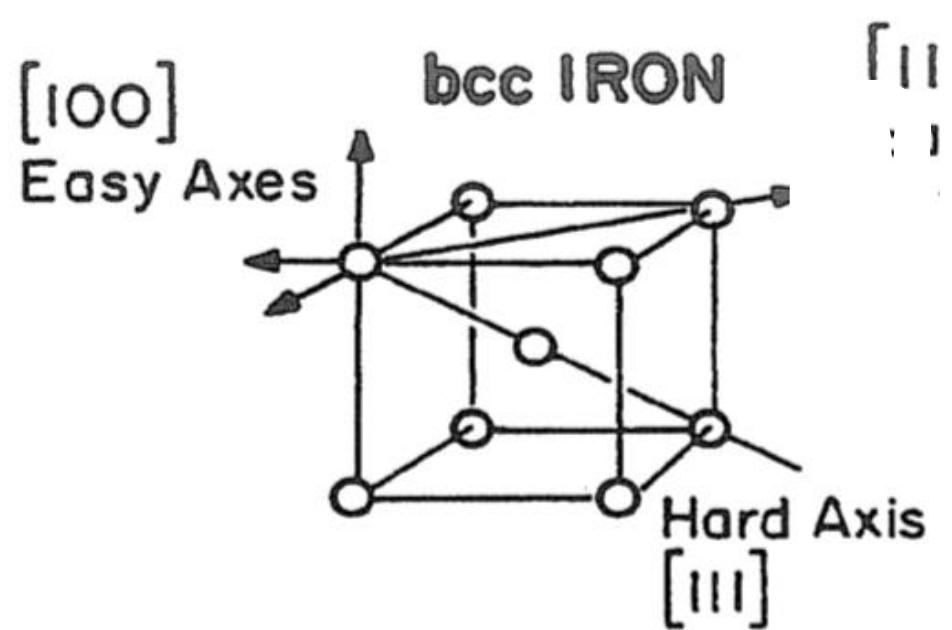


# Phenomenology of Magnetic Anisotropy

## 1. Uniaxial Anisotropy



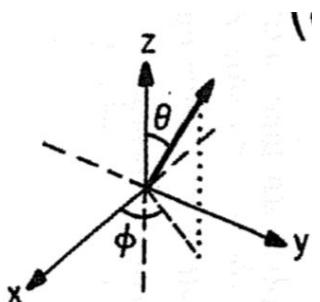
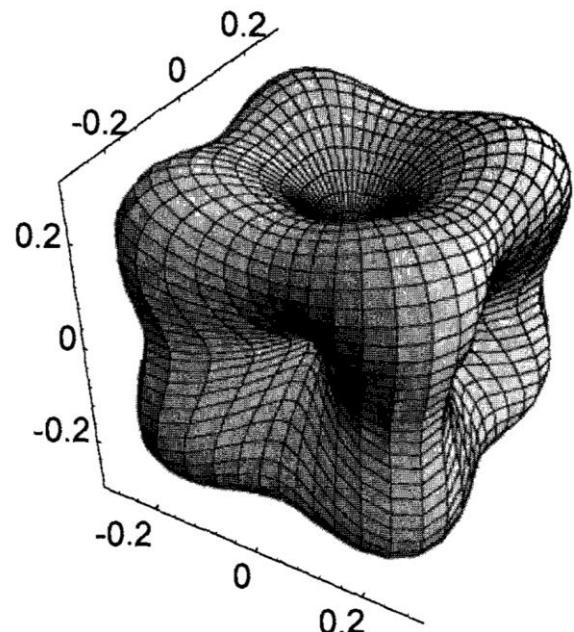
## 2. Cubic Anisotropy



$$u_a = K_0 + K_1(\alpha_1^2 \alpha_2^2 + \alpha_2^2 \alpha_3^2 + \alpha_3^2 \alpha_1^2) + K_2(\alpha_1^2 \alpha_2^2 \alpha_3^2) + \dots$$

$$\alpha_i = \frac{M_i}{M}$$

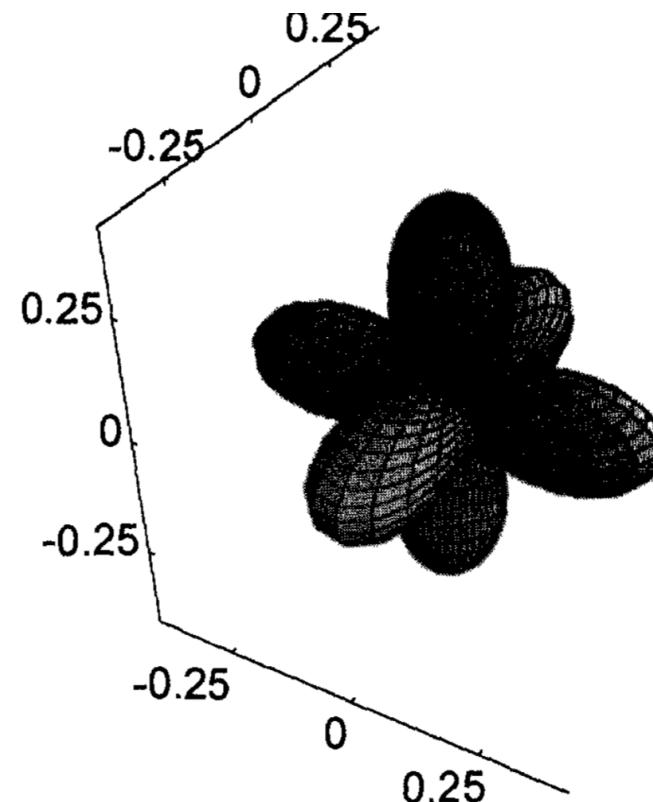
$$K_1 = 4.8 \times 10^4 \quad \text{and} \quad K_2 = -1.0 \times 10^4 \text{ J/m}^3$$



$$K_1 > 0.$$

Easy: <100>; Hard:<111>

$$K_1 = -4.5 \times 10^3 \quad \text{and} \quad K_2 = -2.3 \times 10^3 \text{ J/m}^3$$

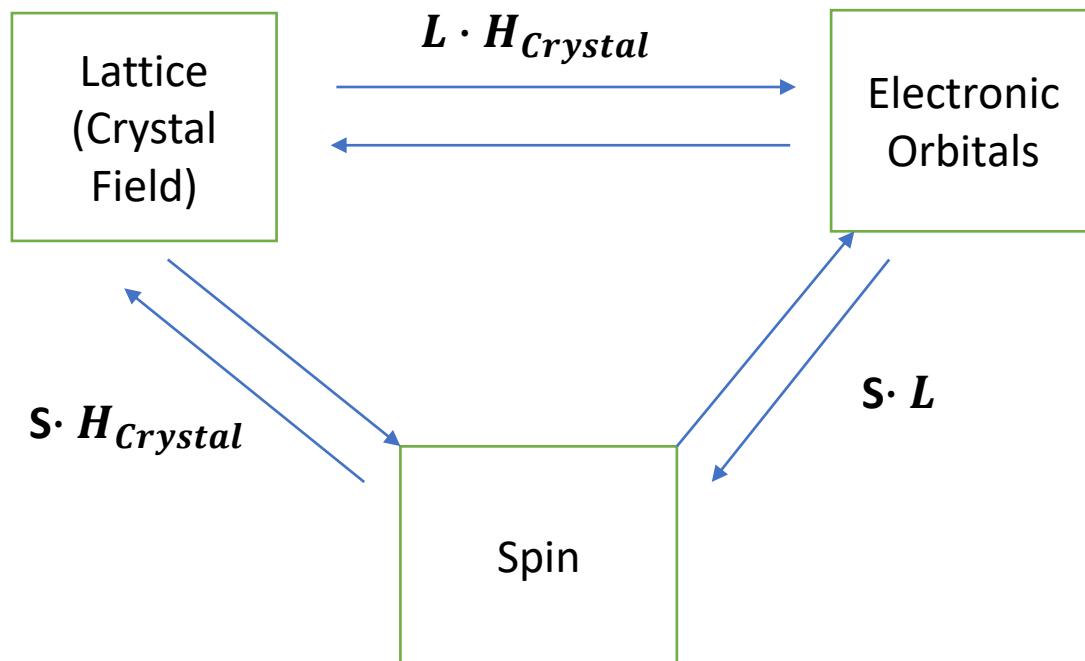


$$K_1 < 0.$$

Easy: <111>; Hard:<100>

# Mechanisms of Magnetic Anisotropy

## 1. Magnetocrystalline Anisotropy



21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn
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	(T = 4.2 K)		(RT)	
	$K_1$	$K_2$	$K_1$	$K_2$
<i>3d Metals</i>				
Fe	$5.2 \times 10^5$	$-1.8 \times 10^5$	$4.8 \times 10^5$	$-1.0 \times 10^5$
Co <sup>u</sup>	$7.0 \times 10^6$	$1.8 \times 10^6$	$4.1 \times 10^6$	$1.5 \times 10^6$
Ni	$-12 \times 10^5$	$3.0 \times 10^5$	$-4.5 \times 10^4$	$-2.3 \times 10^4$
$\text{Ni}_{80}\text{Fe}_{20}$	—	—	$-3 \times 10^3$	—
$\text{Fe}_{50}\text{Co}_{50}$	—	—	$-1.5 \times 10^{5b}$	—

Two limiting responses:

- 1) Crystal Field > SOC,  $\mu_S$  weak anisotropy,  $\mu_L$  quenched, 3d transition metals and alloys
- 2) Crystal Field < SOC,  $\mu_J = \mu_L + \mu_S$ , large anisotropy, rare-earth metal

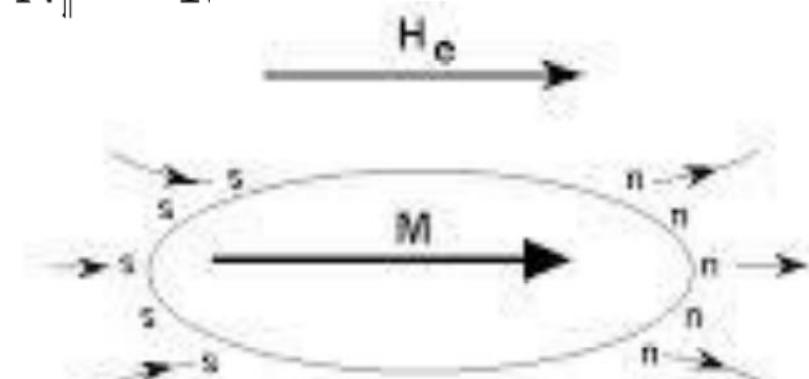
	(T = 4.2 K)		<i>4f Metals</i>
	$K_1$	$K_2$	
$4f^7$	$\text{Gd}^u$	$\langle L_z \rangle = 0$	$-1.2 \times 10^6$
$4f^8$	$\text{Tb}^u$	$\langle L_z \rangle = 3$	$-5.65 \times 10^8$

## 2. Shape Anisotropy

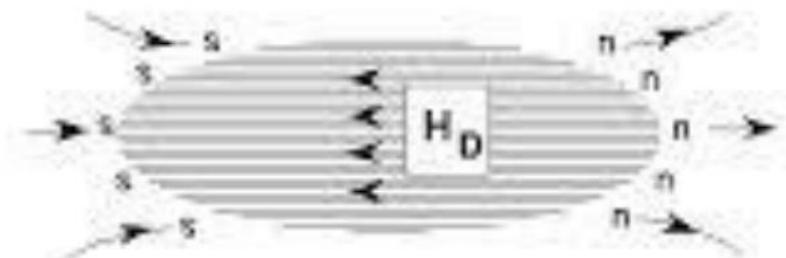
In a homogeneously magnetized spheroid, free energy density

$$u_a = \frac{\mu_0 M^2}{2} (N_\perp \sin \theta^2 + N_\parallel \cos \theta^2) \quad 2N_\perp + N_\parallel = 1.$$
$$= \frac{\mu_0 M^2}{2} N_\parallel + \frac{\mu_0 M^2}{2} (N_\perp - N_\parallel) \sin \theta^2$$

Uniaxial anisotropy!



Magnetization Produces Apparent Surface Pole Distribution



Demagnetizing Field Due to Apparent Surface Pole Distribution

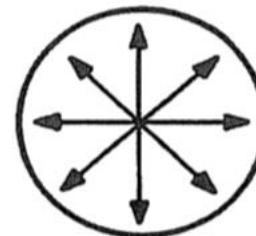
Demagnetizing Field:  $H_{Dj} = N_{ij}M_j$

Demagnetizing factor:  $N_{ij}$

### 3, Inverse Magneto-strictive Effect

For a single crystal of cubic symmetry,

$$u_a = B_1 \sum_i (\alpha_i^2 - \frac{1}{3}) e_{ii} + B_2 \sum_i \alpha_i \alpha_j e_{ii}$$



$$\langle \mathbf{M} \rangle = 0$$

