磁気円二色性で探る
分子・ナノ炭素−磁性金属のスピン状態

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1. はじめに（C_{60}−Co薄膜の巨大磁気抵抗効果）
2. C_{60}−Co薄膜の磁気円二色性分光
3. C_{60}−Co化合物 / 強磁性金属界面の磁気状態
4. まとめ

What’s “Molecular Spintronics”？

スピントロニクス

- 電子の持つスピンの性質を利用（スピン流の生成, 輸送, 制御）
  ⇒　金属系材料を中心に発展

- 非金属系材料(半導体, 有機分子)へ展開
  ⇒　分子スピントロニクス

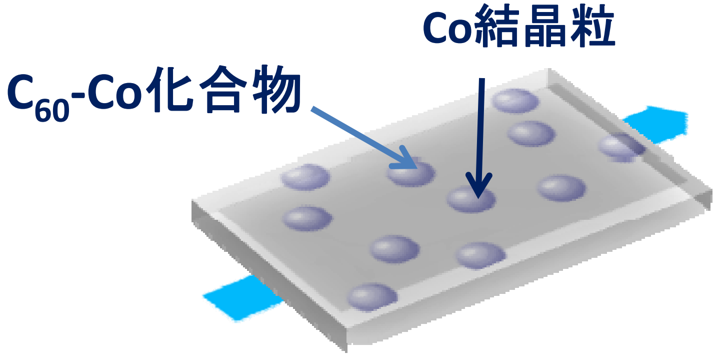
OM/FM interface

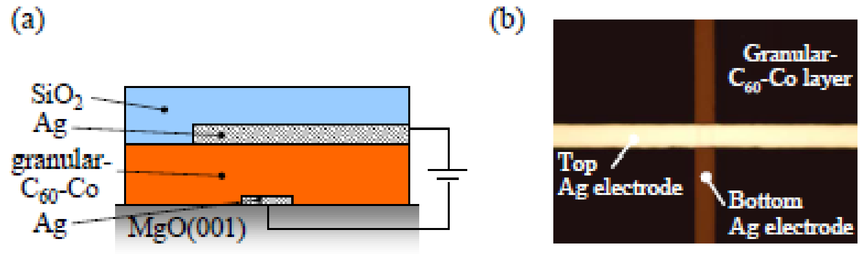
有機分子を使うメリット

- スピン–軌道相互作用、核スピンの影響が小さい
  ⇒　優れたスピン緩和長・時間が期待

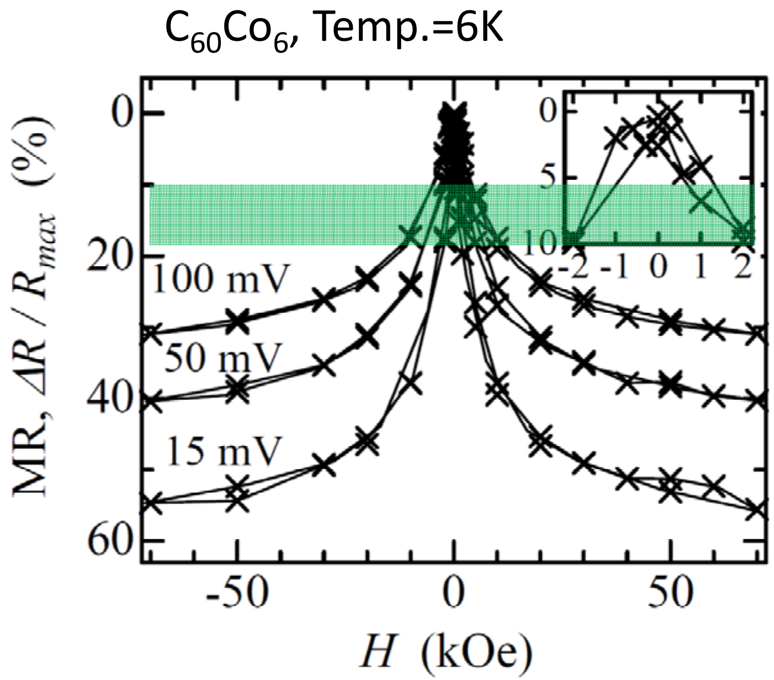
- 分子軌道準位で交換相互作用を制御可能

TMR effect in granular C_{60}–Co film





S. Sakai et al., Phys. Rev. B, 2011



MR = $P^2/(1+P^2)$

P = 34%(Co crystal)

✓ MR(Co @Al-O marix) = ~20%

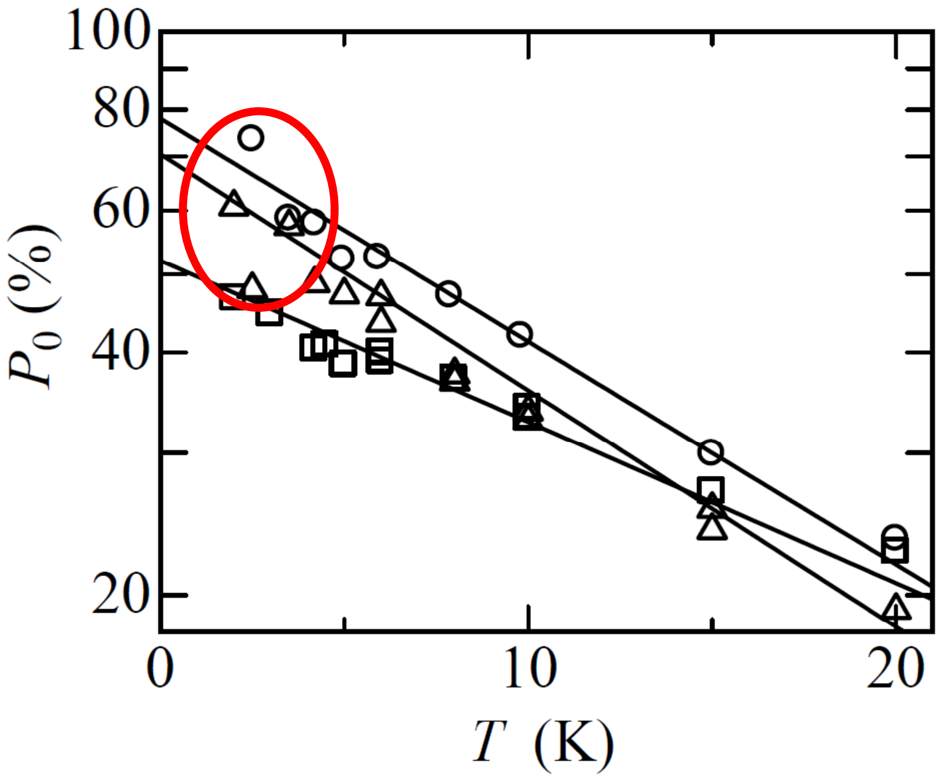
S. Mitani, et al., *Phys. Rev. Lett.* **81** (1998) 2799.

✓ MR(Co @C60 matrix) = ~30%

H. Zare-Kolsarakia, *Eur. Phys. J. B* **40**,103 (2004).

TMR effect in granular C_{60}–Co film

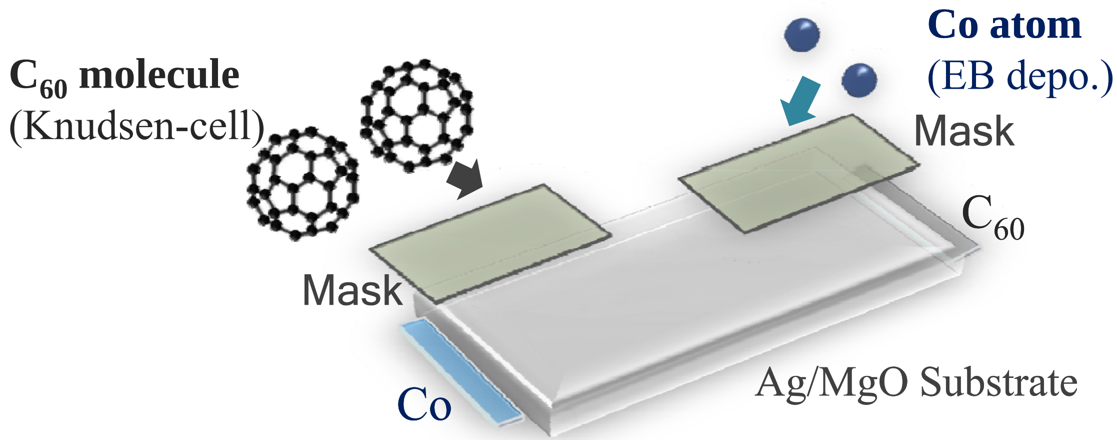
Spin polarization of tunnel electrons

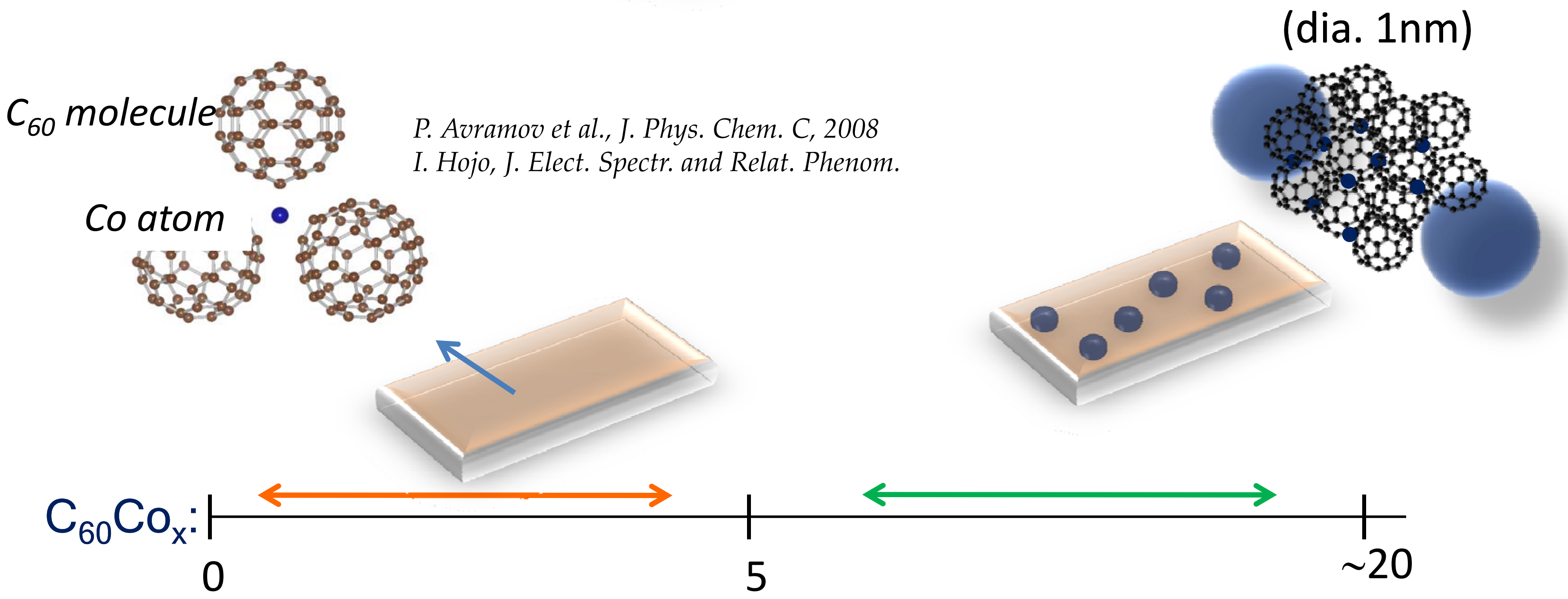


Zero-bias spin polarization vs. temperature for three different samples ($C_{60}Co_6$, $C_{60}Co_7$ and $C_{60}Co_8$)

S. Sakai et al., Phys. Rev. B, 2011

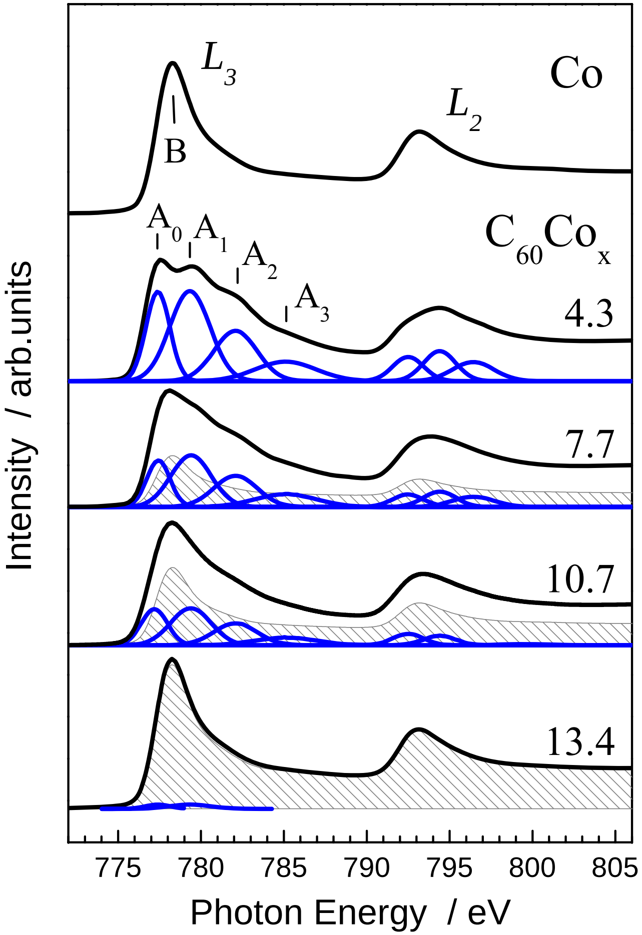
TMR effect in granular C_{60}–Co film





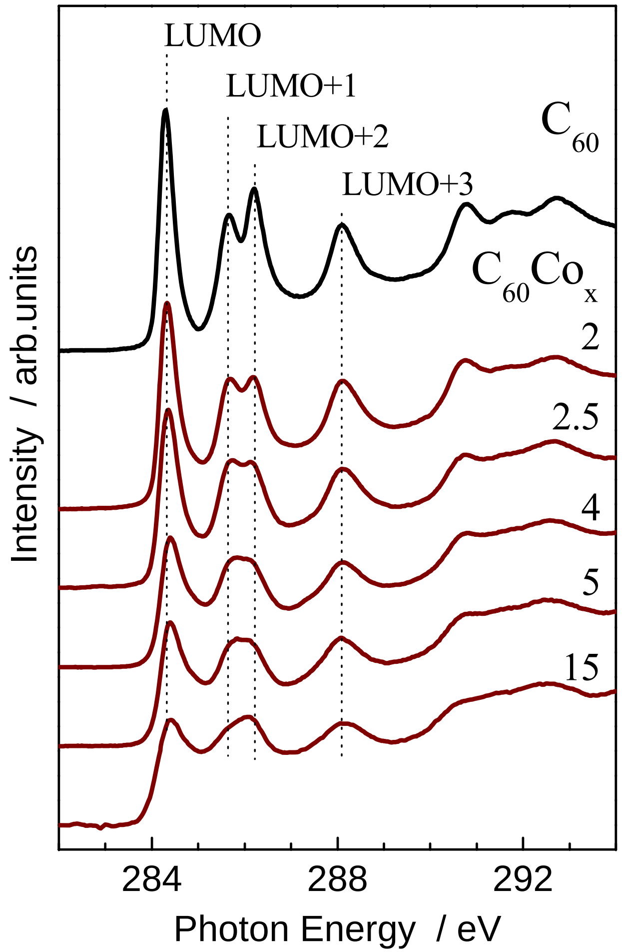
P. Avramov et al., J. Phys. Chem. C, 2008
I. Hojo, J. Elect. Spectr. and Relat. Phenom.

Co *L*-edge and C *K*-edge XAFS



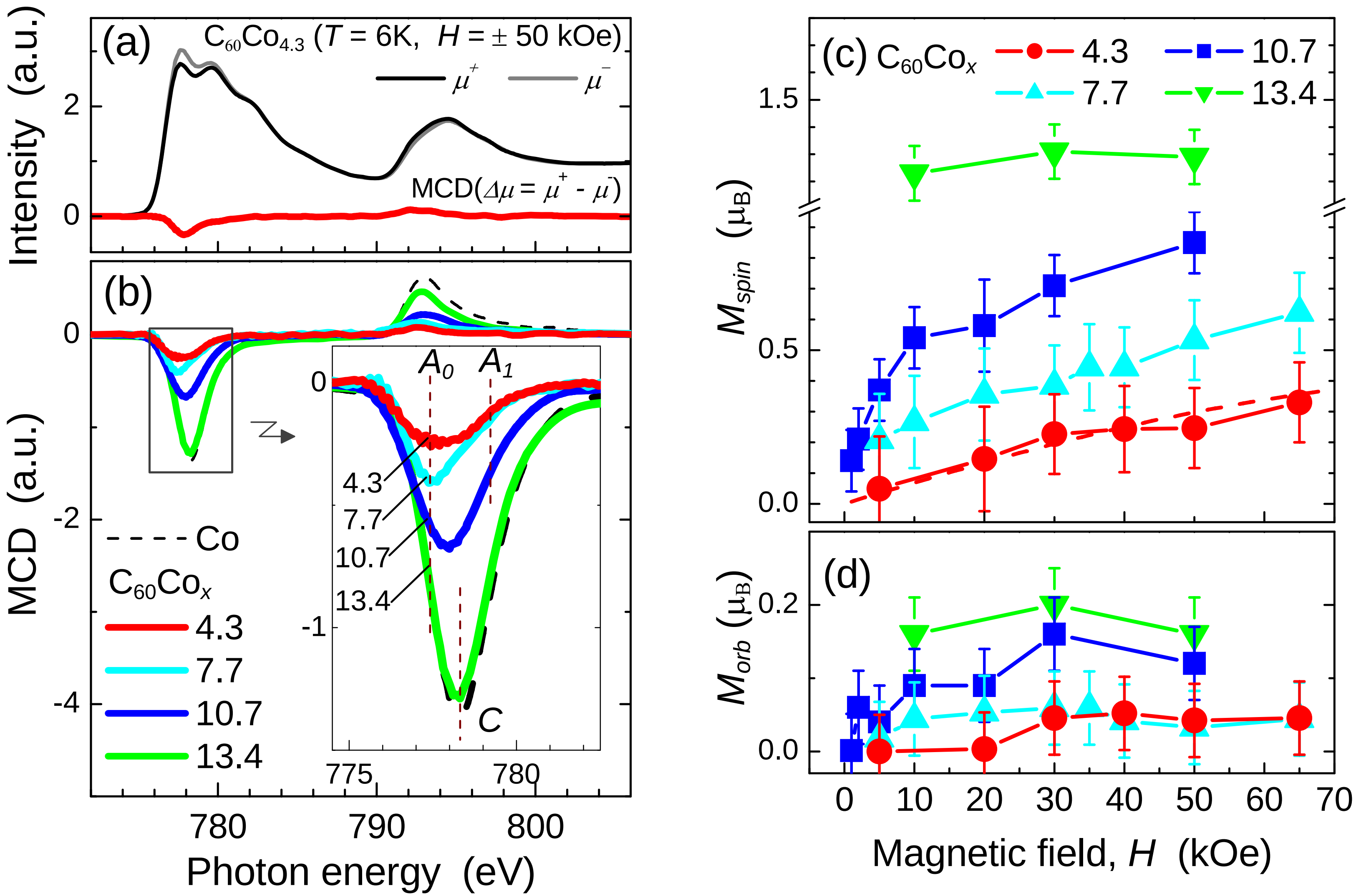
Multiplet splitting of Co 3d levels

(777.6, 779.2, 781.9, 785.3 eV@L_3-edge)

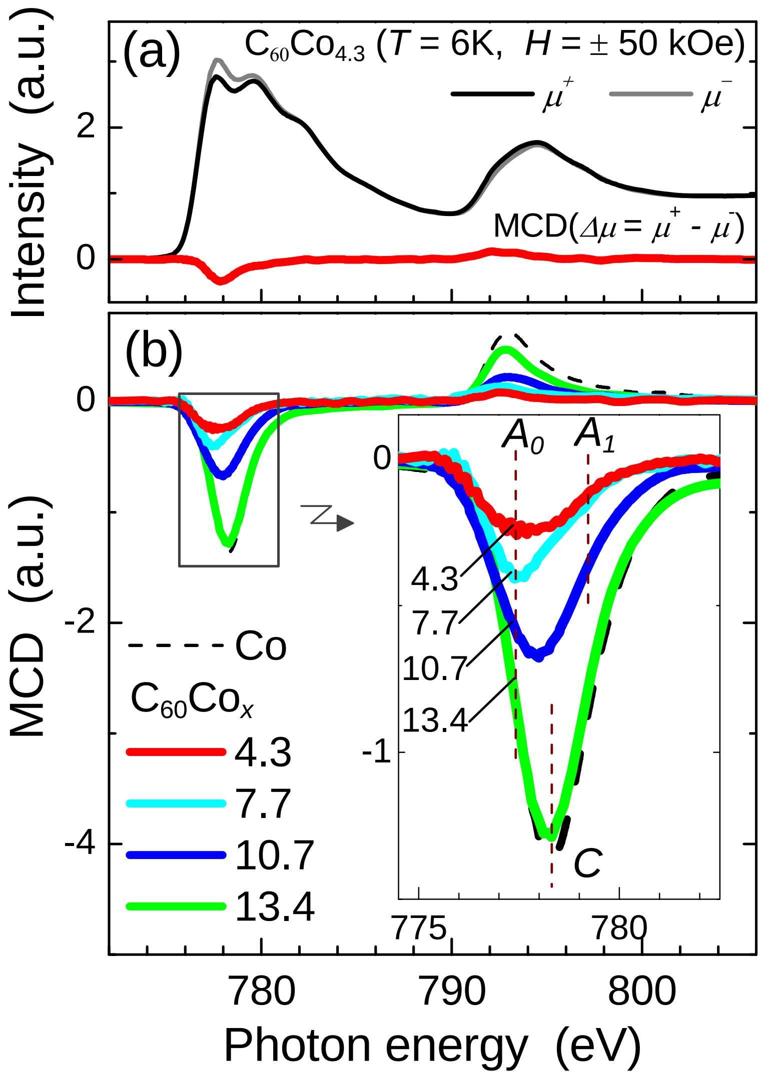


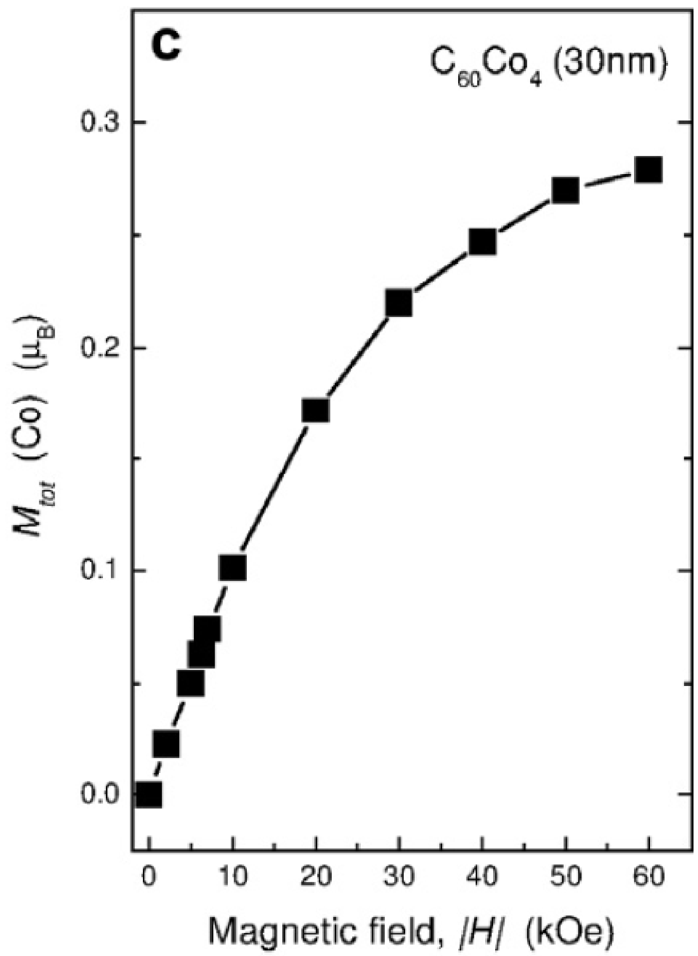
Distortion of C_{60} molecule

XMCD spectra of C_{60}–Co films



XMCD spectra of C_{60}–Co films





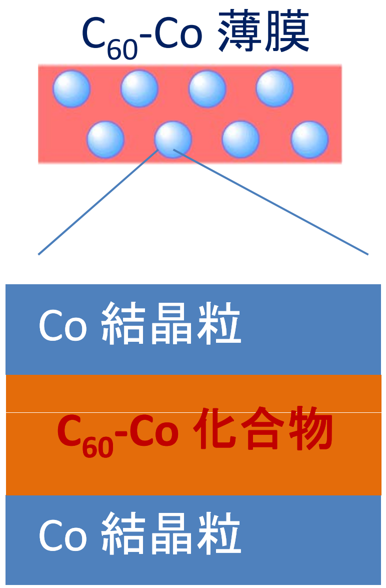
T-dependence of MR

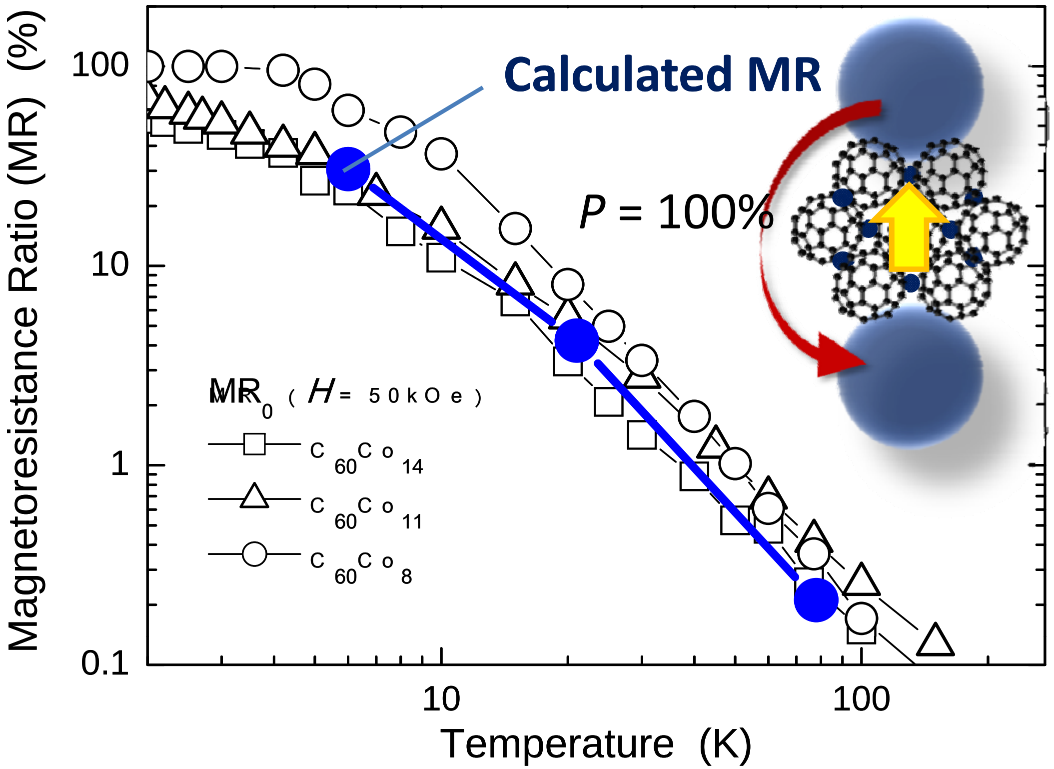
MRの理論モデル: MR = $P^2 / (1+P^2) = m^2P^2 / (1 + m^2P^2)$

S. Mitani et. al, PRL **81** (1998) 2799. J.Inoue and S. Maekawa, PRB **53** (1996) R11927.

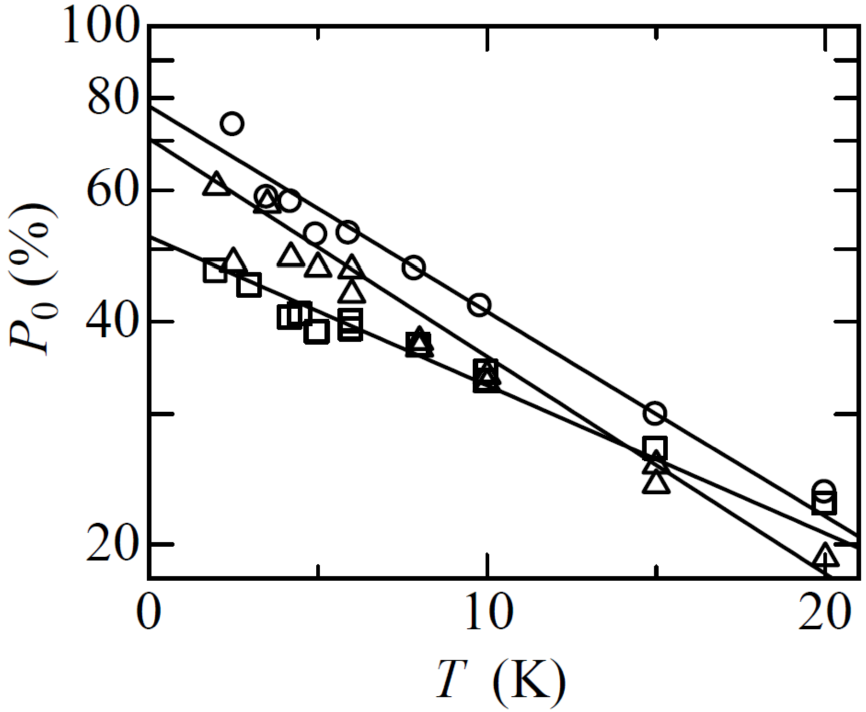
C_{60}-Co化合物の局在dスピンの影響を仮定

$m = M_{tot} / M_{sat}$, P = ~100%

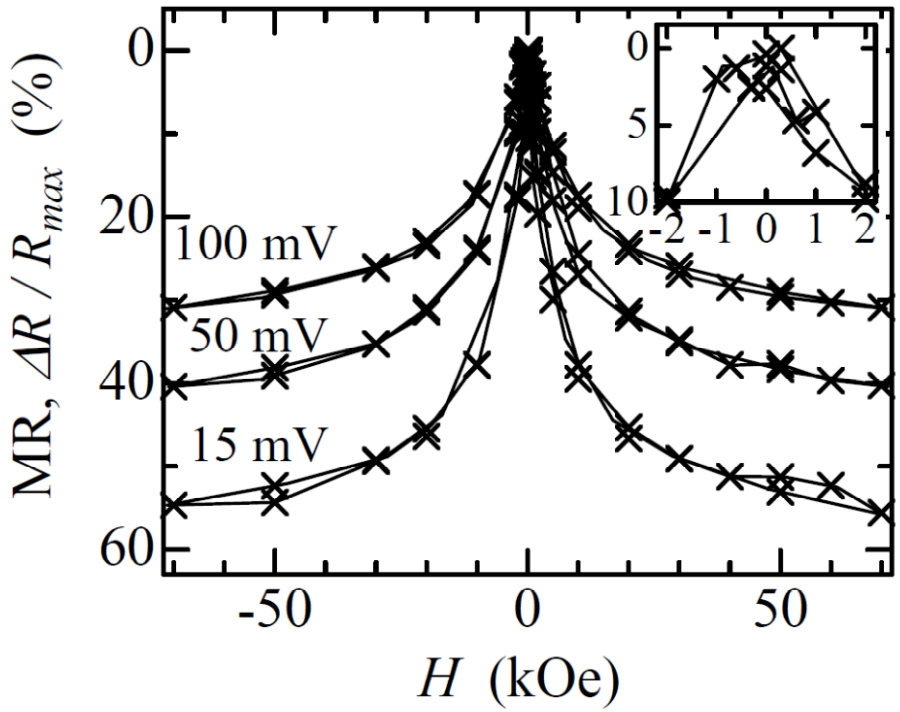




Spin polarization of tunnel electrons



MR of granular C_{60}-Co films



MRの**温度依存性**:　C_{60}-Co化合物中の局在dスピンに強く依存

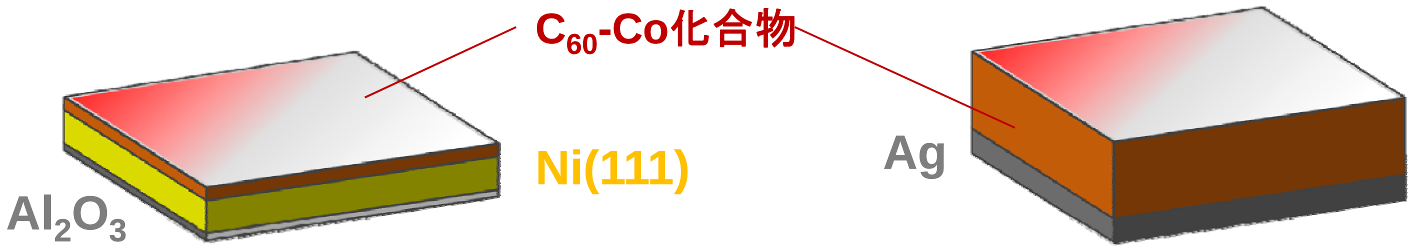
MRの**磁場依存性**:　Co結晶粒の磁気的応答に類似

C_{60}–Co化合物/Co結晶粒界面の磁気状態

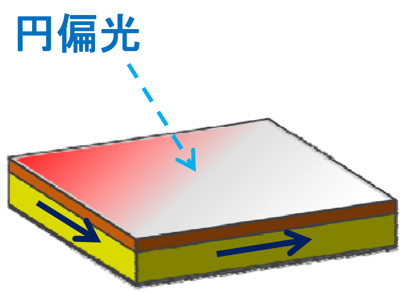
C_{60}–Co compound /Ni structure

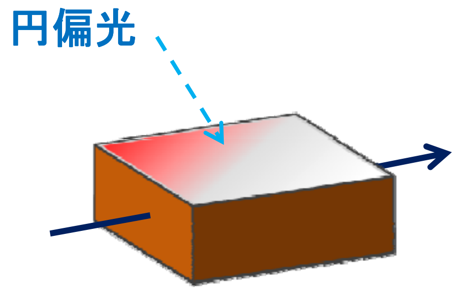
✓ C_{60}-Co化合物薄膜/磁性金属の積層試料

(A) **C_{60}-Co 化合物 (3-5nm)** / **Ni(111)**　　(B) **C_{60}-Co 化合物** (30nm) / **Ag**



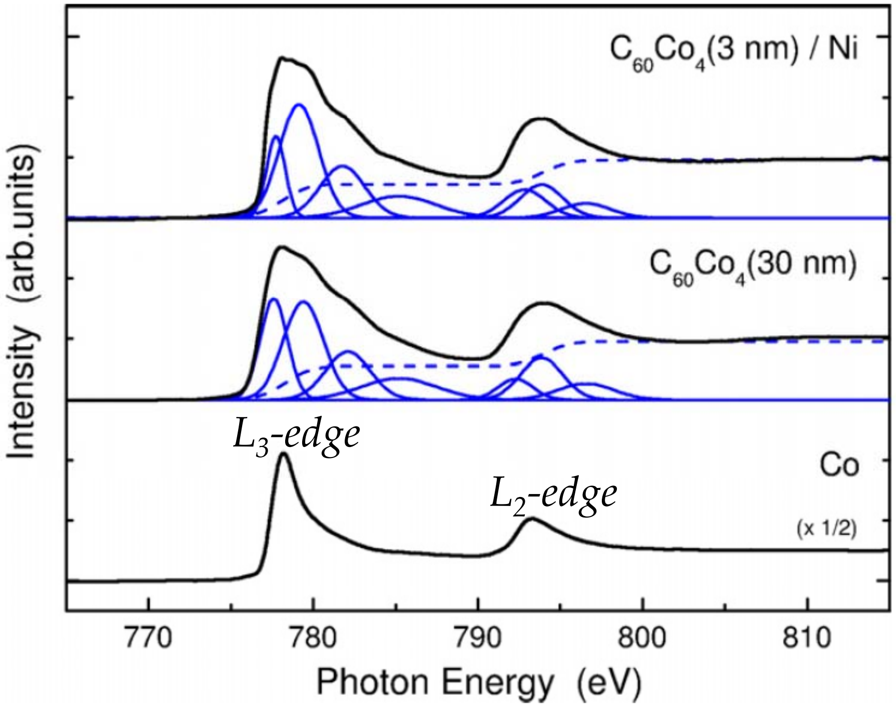
✓磁気円二色性測定方法





Ni磁化させた後、H=0kOeで測定　　超伝導Mgにより、外部磁場を印加

Co L-edge XAFS of $C_{60}Co_4$ with/without Ni

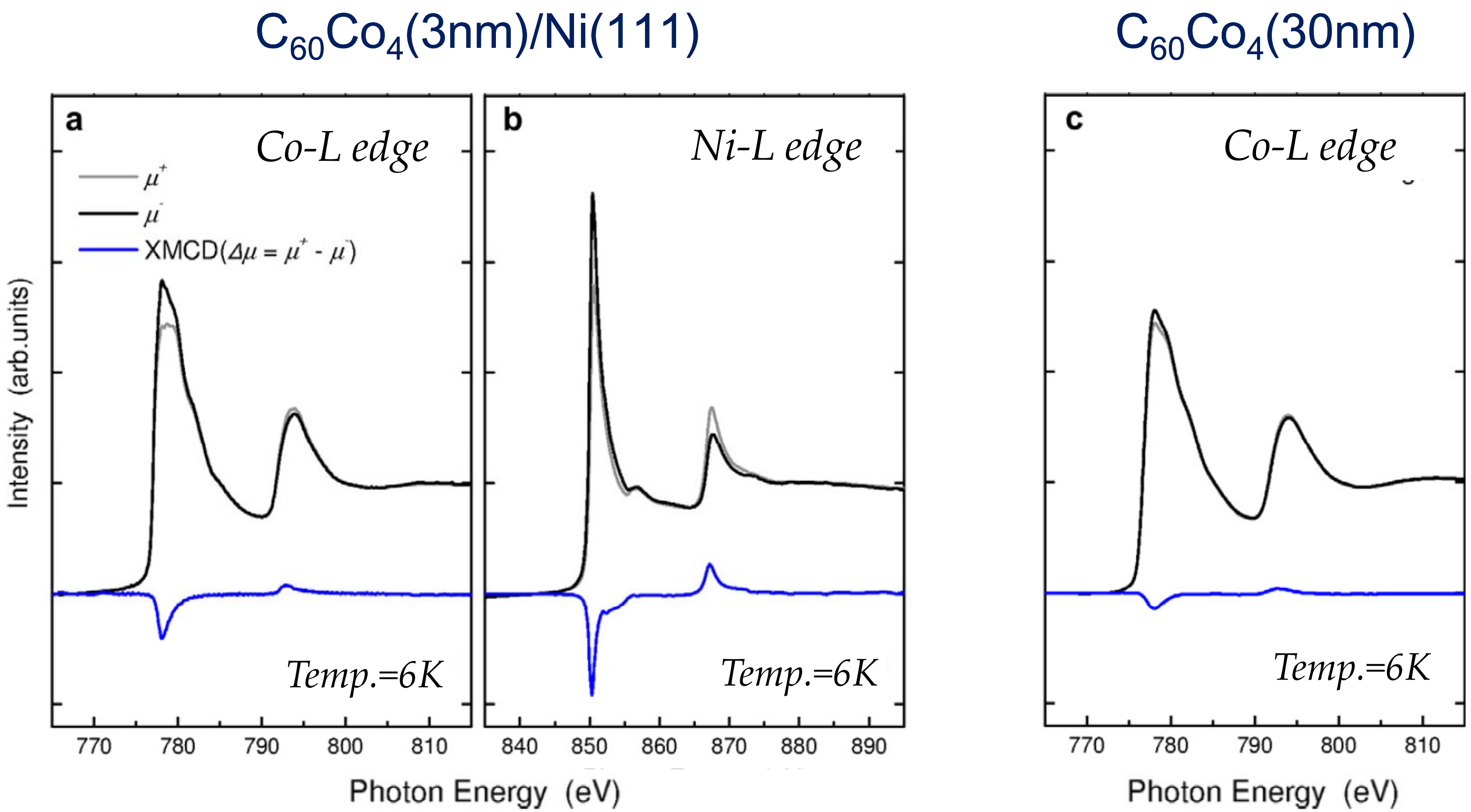


$C_{60}Co_4$(3nm)/Ni(111)

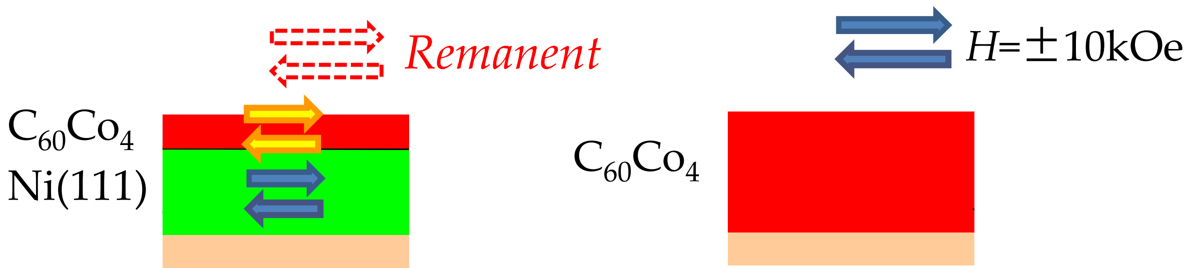
$C_{60}Co_4$(30nm)

Co crystal
(778.2 eV@L_3-edge)

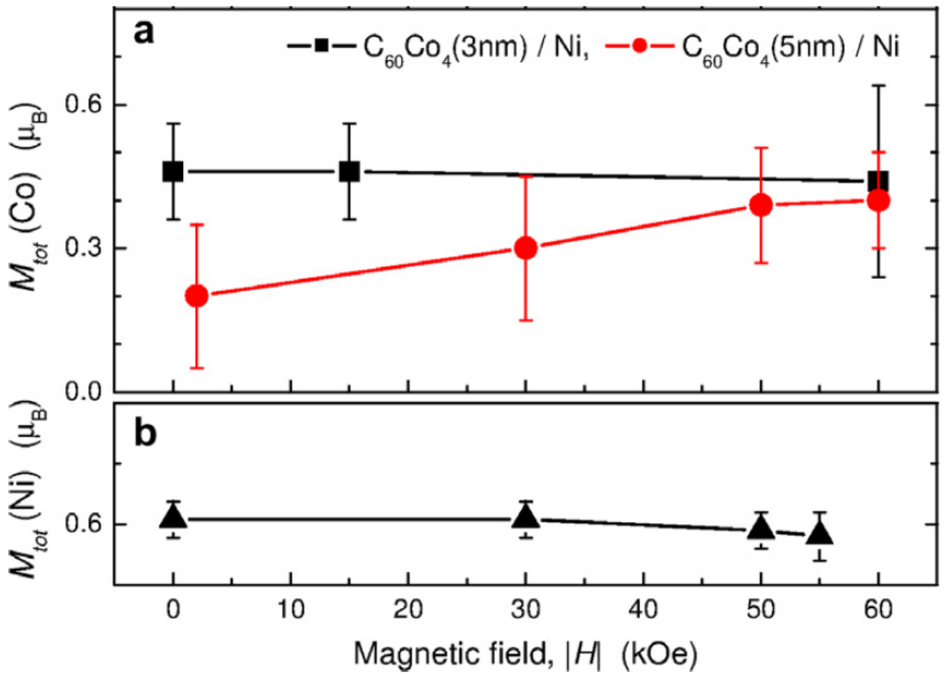
XMCD of $C_{60}Co_4$ with/without Ni



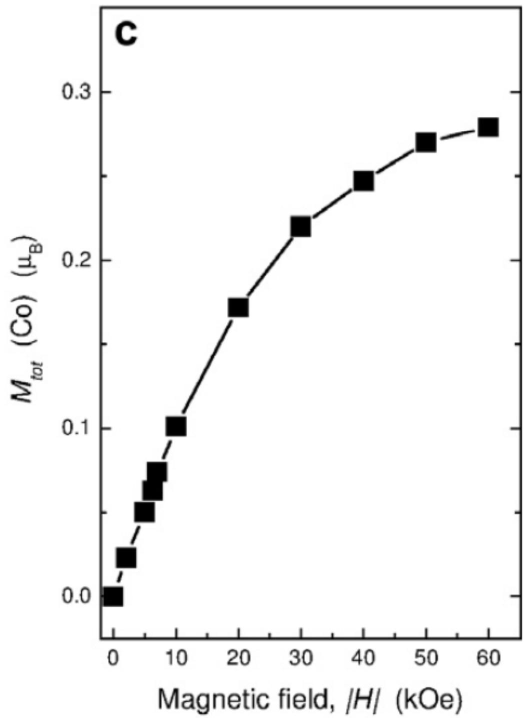
Ferromagnetism
by Co d-electron spins



Field dependence of magnetization of $C_{60}Co_4$/Ni



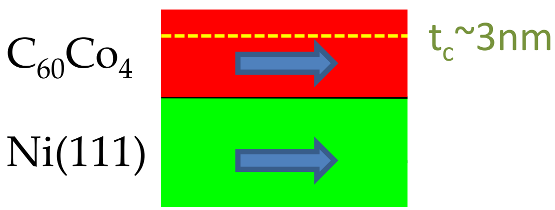
$C_{60}Co_4$(3nm, 5nm)/Ni(111)



$C_{60}Co_4$(30nm)

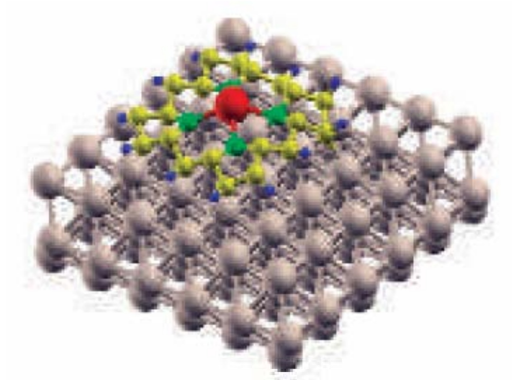
Ferromagnetic coupling of Co d-spins to Ni layer

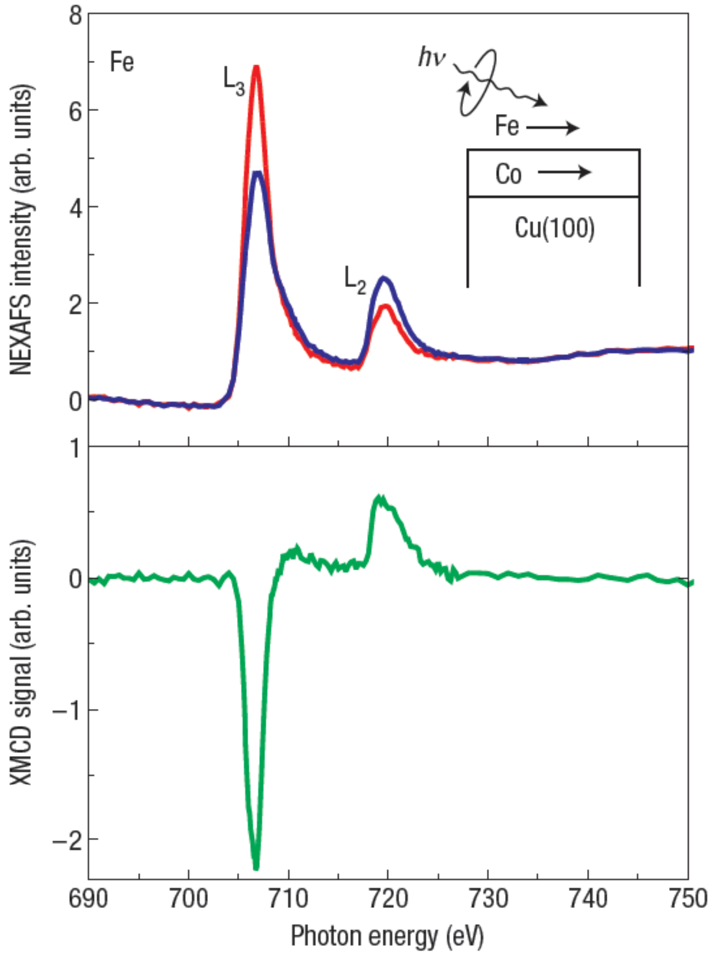
- Critical thickness $t_c \approx 3$nm
- Stable up to 100 K



XMCD of iron porphyrin monolayer adsorbed on Co

H. Wende et al., nature mater., 2007

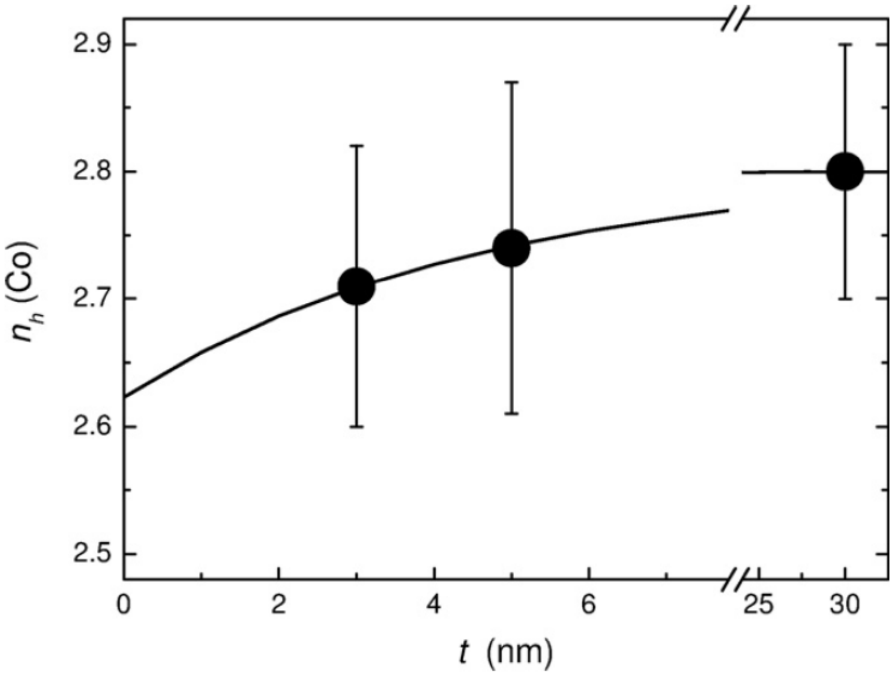




(Top) Schematic of Fe OEP molecules on Co surface
(Right) Fe L-edge XAS and XMCD spectra

Localized Fe spins are ferromagnetically coupled to Co

Co 3d N_h vs. $C_{60}Co_4$ layer thickness

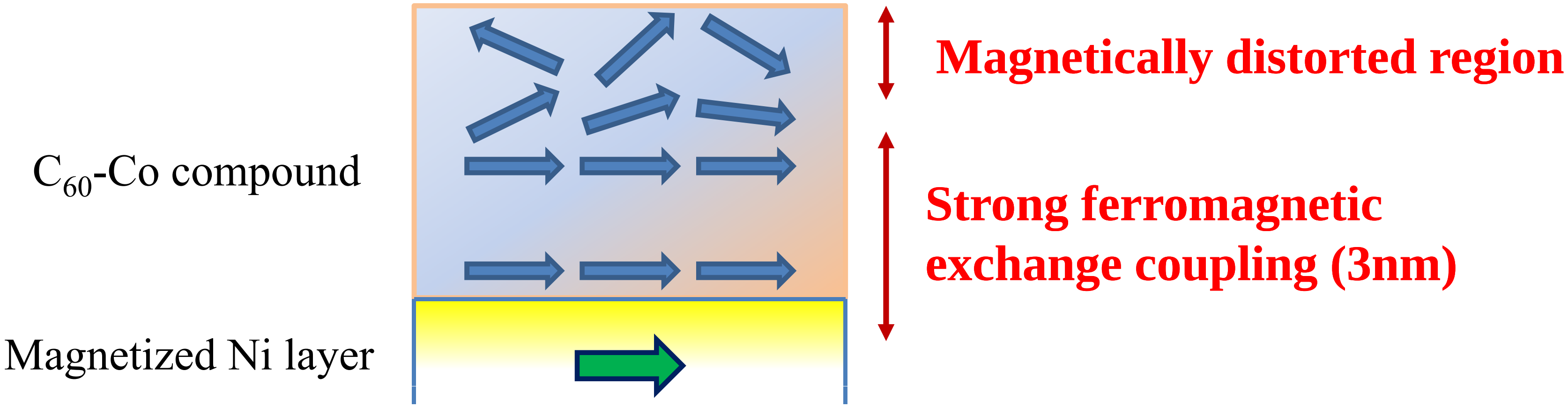


– 膜厚(t)の減少と共にCo 3d電子が増加

Occupation of Co 3d orbitals
by transferred electrons from Ni layer

Critical thickness $t_C \approx 4$ nm

Electronic and magnetic properties of C_{60}-Co films and C_{60}-Co compound / FM interface



Long range Interlayer ferromagnetic coupling

Charge transfer : FM → C_{60}-Co compound

~ Mechanism of high spin polarization at interface