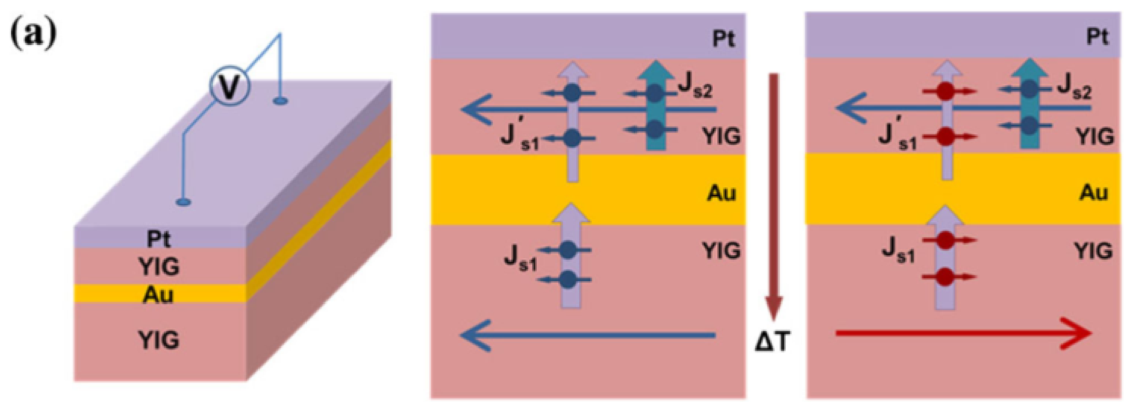
# 1. 磁子晶体管

The transistor—a device that controls the flow of electrons in a circuit—is the cornerstone of modern electronics.Electronic transistors control flows of electric charge in a computer chip. The smaller the transistors, the faster the chip operates, but quantum mechanics sets a minimum size. To continue improving performance, researchers are turning to alternatives, such as replacing electronic circuits with so-called magnonic circuits.

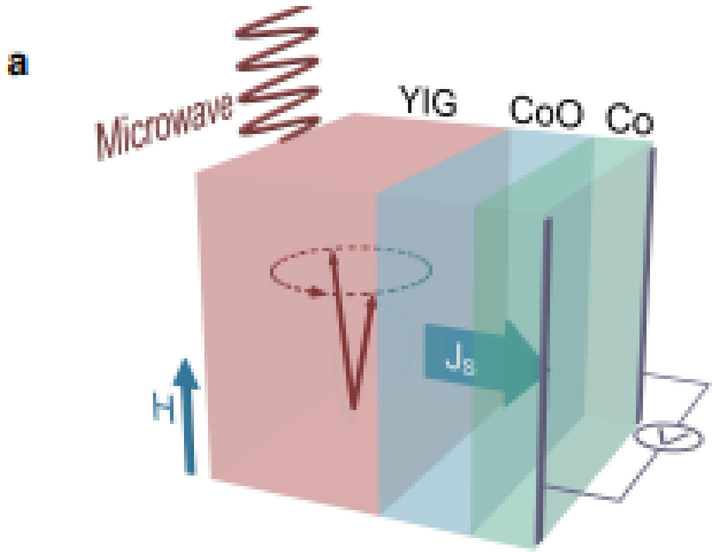
Magnonic devices run exclusively on spin currents. (Spintronic devices, another electronics alternative, include both charge and spin currents.) To picture a magnon, imagine a row of spins pointing up, representing a magnetic material, and then imagine briefly flipping the spin at one end. This motion leads to a propagating wave that moves through the material as each spin influences its neighbor. Magnons can travel quickly and efficiently over long distances—up to about a centimeter in the best materials—without significantly losing energy or heating up the material, a feat not possible for electrons. But before building fast and efficient magnonic circuits, researchers need components that can regulate magnon currents.

There are three main magnon transistors as follows:

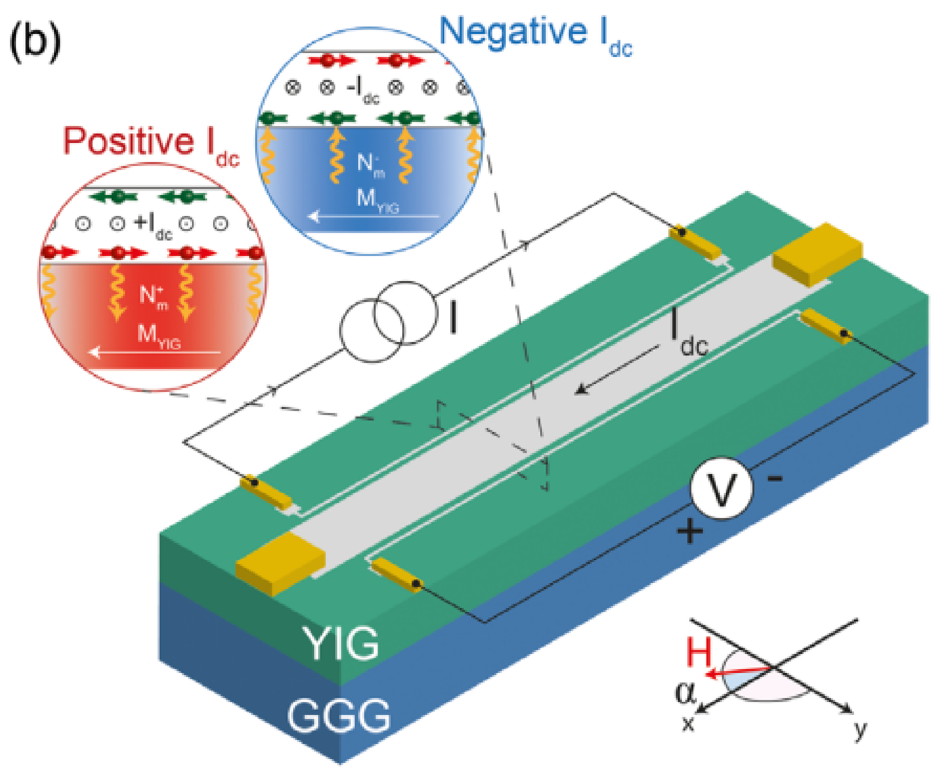
1. The magnon transistor developed by Xiufeng Han（也叫磁子阀）and colleagues at the Chinese Academy of Sciences in Beijing is a trilayer structure in which a nonmagnetic gold layer is sandwiched between two insulating ferromagnetic layers made of yttrium iron garnet (YIG). To test the device, the team applied a temperature gradient across the sandwich to generate magnons in the YIG layers. With those two layers magnetically aligned, the team measured a large magnon current, whereas the current was up to 32% smaller when the two YIG layers had antiparallel alignment.




2. The second valve transistor, made by Mathias Kläui of Johannes Gutenberg University of Mainz in Germany and colleagues, acts in a similar way to that of Han and co-workers, but it contains different materials—it’s a cobalt/cobalt oxide/YIG trilayer—and it generates magnons in only one layer of the device (the YIG layer). Comparing the magnon current transmitted when the cobalt and YIG layers had parallel alignments with that of the antiparallel alignment, the team measured a 290% difference.




3. The third new transistor is a thin rectangle of platinum on top of a larger square of YIG, and it functions differently from the valves. Rather than using magnetic effects, Ludo Cornelissen of the University of Groningen in the Netherlands and colleagues used an electric current to vary the magnon current. In their device, the magnons are generated at one end of the YIG square and detected at the other. Additional magnons are pumped into or absorbed from the YIG depending on the spin direction of the electrons flowing in the platinum strip. When these electrons' spins are aligned with the YIG magnons, the magnon current increases; when oppositely aligned, the magnon current decreases.




来源：https://physics.aps.org/articles/v11/23

## 2.A4 纸的尺寸

210 mm × 297 mm

# 3. 自旋泵浦

自旋泵浦 (spin pumping) 是指在铁磁/非磁性金属双层薄膜结构中，铁磁体在一定的外加恒定磁场和一定频率的微波磁场作用下会发生强烈的共振现象 (铁磁共振)，当局域磁矩处于共振态时，在铁磁层与非磁性金属层的界面处会存在自旋泵浦效应，即局域磁矩通过在这个界面的交换耦合作用以进动的方式向非磁金属层中泵入自旋角动量，从而向邻近的非磁性金属层中泵浦出一个交变的自旋流，经过时间平均以后会产生一个直流的自旋流，这个直流的自旋流通过金属层中的逆自旋霍尔效应最终转换成一个电压信号，同时使铁磁体产生额外的阻尼项。铁磁体磁化强度矢量受到微扰会有自旋波激发产生，并在铁磁体内传播过程中不断衰减 (称为 Gilbert 阻尼)，而调节能量源 (即微波) 的频率达到磁性材料的共振频率，可以弥补对应频率磁振子的能量损失，使得自旋流维持下去。

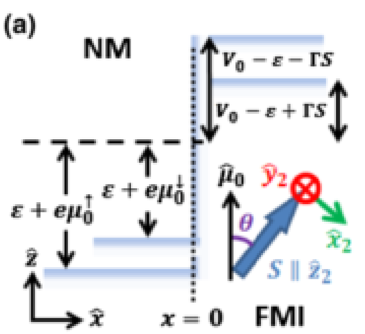
功能：测量磁性材料磁化强度的变化，广泛应用于定性或定量研究相关材料的多种自旋输运参数，例如自旋扩散长度、自旋霍尔角、阻尼因子、界面自旋混合电导，等等。

# 4.Utrecht University

荷兰乌得勒支大学，Rembert A. Duine 就职于该大学。

# 5. 自旋混合电导

自旋混合电导是表征自旋-磁子转换效率的一个物理量，它的实部对应 damping，虚部对应场。从金属层透射到磁性绝缘体层的自旋分成垂直于和平行于磁性绝缘层局域磁矩的两个部分，其中垂直的那一部分分成 damgping 项和场项，分别对应于自旋混合电导的实部与虚部，这一部分无法透过铁磁绝缘层，平行的那一部分可以透过铁磁绝缘层。




$$\langle\sigma^{x_2,y_2}\rangle = -4\frac{|A|^2}{|\gamma_\theta|^2}\sin\theta\, e^{-(q_+ + q_-)x}(\mathrm{Re},\mathrm{Im})(n_{\downarrow+}^* n_{\downarrow-}),$$
$$\langle\sigma^{z_2}\rangle = 2\frac{|A|^2}{|\gamma_\theta|^2}\cos\theta\, e^{-(q_+ + q_-)x} \times [(|n_{\downarrow+}|^2 - |n_{\downarrow-}|^2) + (|n_{\downarrow+}|^2 + |n_{\downarrow-}|^2)\cos\theta]. \quad (4)$$

$$\boldsymbol{\tau} = \frac{\Gamma}{\hbar}\langle\bar{\boldsymbol{\sigma}}\rangle \times \mathbf{S} = \frac{\Gamma}{\hbar}S\langle\bar{\sigma}^{y_2}\rangle\hat{\mathbf{x}}_2 - \frac{\Gamma}{\hbar}S\langle\bar{\sigma}^{x_2}\rangle\hat{\mathbf{y}}_2 = \frac{\Gamma S a^2 N_F}{\hbar}[G_r\hat{\mathbf{S}}\times(\hat{\mathbf{S}}\times\boldsymbol{\mu}_0) + G_i\hat{\mathbf{S}}\times\boldsymbol{\mu}_0]$$
$$G_{r,i} = \int_0^\infty \frac{\langle\sigma^{y_2,x_2}\rangle}{N_F|\boldsymbol{\mu}_0|\sin\theta}dx = -4\frac{(\mathrm{Im},\mathrm{Re})(n_{\downarrow+}^* n_{\downarrow-})}{a^3|\gamma_\theta|^2(q_+ + q_-)}, \quad (5)$$

参考文章：Minimal Model of Spin-Transfer Torque and Spin Pumping Caused by the Spin Hall Effect

# 6. 离心率与圆锥曲线的关系

离心率为 0 为圆，离心率为 1 为抛物线，离心率 >1，为双曲线，离心率大于 0 小于 1，为椭圆。

# 7. 热力学极限

热力学极限是指粒子数（或体积）趋向无穷大时的极限。

# 8. 费米黄金规则（Fermi's golden rule）

# 费米黄金规则 Fermi's Golden Rule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Chemical Physics



First off, **Fermi's golden rule (FGR)** should be called Dirac's golden rule, although the FGR is more popular in the scientific community. FGR is the formulation of the quantum transition rate between the initial $|i\rangle$ and the final $|f\rangle$ states based on the **time-dependent perturbation theory**. We show the derivation of FGR in different cases below.

## 1. Transition probability from state $|i\rangle$ to state $|f\rangle$

We consider the total Hamiltonian $H$ is equal to the sum of the unperturbed $H_0$ and the perturbation $W(t)$ :

$$H = H_0 + W(t). \tag{1}$$

Suppose the wavefunctions $\{|\phi_n\rangle\}$ are the eigenfunctions of the unperturbed $H_0$ , namely

$$H_0|\phi_n\rangle = E_n|\phi_n\rangle, \tag{2}$$

then the corresponding wavefunctions at time $t$ are given by

$$|\psi_n(t)\rangle = |\phi_n\rangle e^{-iE_nt/\hbar}. \tag{3}$$

The time-dependent Schrodinger equation for the entire system's wavefunction $|\psi(t)\rangle$ is

$$H|\psi(t)\rangle = [H_0 + W(t)]|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle \tag{4}$$

where the $|\psi(t)\rangle$ expressed as the linear combination of the $\{|\phi_n\rangle\}$ basis is given by

$$|\psi(t)\rangle = \sum_n c_n(t)|\psi_n(t)\rangle = \sum_n c_n(t)|\phi_n\rangle e^{-iE_nt/\hbar} \tag{5}$$

Plug Eq (5) into Eq (4), we have

$$[H_0 + W(t)] \sum_n c_n(t)|\phi_n\rangle e^{-iE_nt/\hbar} = i\hbar\frac{\partial}{\partial t} \sum_n c_n(t)|\phi_n\rangle e^{-iE_nt/\hbar}$$
$$\Rightarrow \qquad \sum_n c_n(t)E_n|\phi_n\rangle e^{-iE_nt/\hbar} + \sum_n c_n(t)W(t)|\phi_n\rangle e^{-iE_nt/\hbar}$$
$$= i\hbar \sum_n \frac{\partial c_n(t)}{\partial t}|\phi_n\rangle e^{-iE_nt/\hbar} + i\hbar \sum_n c_n(t)|\phi_n\rangle \left(-\frac{iE_n}{\hbar}\right) e^{-iE_nt/\hbar}$$

Then we apply $\langle\phi_k|$ on the left of the above equation and obtain

$$c_k(t)E_k e^{-iE_kt/\hbar} + \sum_n c_n(t)W_{kn}(t)e^{-iE_nt/\hbar}$$
$$= i\hbar\frac{\partial c_k(t)}{\partial t}\rangle e^{-iE_kt/\hbar} + c_k(t)E_k e^{-iE_kt/\hbar}$$

rearranging the above result and denoting matrix element $W_{kn}(t) = \langle\phi_k|W(t)|\phi_n\rangle$ and frequency $\omega_{kn} = (E_k - E_n)/\hbar$ , we have

$$\frac{\partial c_k(t)}{\partial t} = \frac{1}{i\hbar}\sum_n c_n(t)W_{kn}(t)e^{i\omega_{kn}t} \tag{6}$$

Now we assume that (a) the initial state is $|i\rangle$ which means only the $c_i(0) = 1, c_{j\neq i}(0) = 0$ and (b) the perturbation is weak and the coefficients do not change much during time $t$ , from Eq (6)

$$\frac{\partial c_k(t)}{\partial t} = \frac{1}{i\hbar}c_i(t)W_{ki}(t)e^{i\omega_{ki}t} \tag{7}$$

So for any final state $|f\rangle$ , the coefficient will be

$$\boxed{c_f(t) = \frac{1}{i\hbar}\int_0^t W_{fi}(\tau)e^{i\omega_{fi}\tau}d\tau} \tag{8}$$

and the probability of finding the system in the state $|f\rangle$ given the initial state is $|i\rangle$ is thus

$$\boxed{P_{i\to f}(t) = |\langle\phi_f|\psi(t)\rangle|^2 = \frac{1}{\hbar^2}\left|\int_0^t e^{i\omega_{fi}\tau} W_{fi}(\tau) d\tau\right|^2} \tag{9}$$

## 2. Transition probability for a constant perturbation

If the perturbation $W(t) = W\Theta(t)$ is switched on and keep constant after time $0$ , where $\Theta(t) = \begin{cases} 0, & (t<0) \\ 1, & (t \geq 0) \end{cases}$ is the Heaviside step function, we can simplify Eq (9) and

$P_{i\to f}(t) = \frac{1}{\hbar^2}\left|W_{fi}\int_0^t e^{i\omega_{fi}\tau} d\tau\right|^2 = \frac{1}{\hbar^2}|W_{fi}|^2\left|\frac{e^{i\omega_{fi}t-1}}{\omega_{fi}}\right|^2$ .

Using $|e^{i\theta}-1|^2 = 4\sin^2(\theta/2)$ , we have

$$P_{i\to f}(t) = \frac{1}{\hbar^2}|W_{fi}|^2\left(\frac{\sin(\omega_{fi}t/2)}{\omega_{fi}/2}\right)^2 \tag{10}$$

At the $t \to \infty$ limit, we use the asymptotic relation of the delta function $\delta(x) = \lim_{t\to\infty}\frac{\sin^2(xt)}{\pi x^2 t}$ , and $\delta(\omega_{fi}/2) = 2\hbar\delta(\hbar\omega_{fi}) = 2\hbar\delta(E_f - E_i)$ , we have

$\left(\frac{\sin(\omega_{fi}t/2)}{\omega_{fi}/2}\right)^2 = 2\pi\hbar t\delta(\hbar\omega_{fi}) = 2\pi\hbar\delta(E_f - E_i)$

So the transition probability in Eq (10) reduces to

$$P_{i\to f}(t) = \frac{2\pi t}{\hbar}|W_{fi}|^2\delta(E_f - E_i) \tag{11}$$

The transition rate is then defined as the transition probability per unit time:

$$\boxed{\Gamma_{i\to f} = \frac{dP_{i\to f}(t)}{dt} = \frac{2\pi}{\hbar}|W_{fi}|^2\delta(E_f - E_i)} \tag{12}$$

If the final state is a continuum one with the density of states $\rho(E_f)$ (number of states per unit energy interval), the total transition rate $R_{i\to f}$ can be obtained from

$R_{i\to f} = \int \Gamma_{i\to f}\rho(E_f)dE_f = \frac{2\pi}{\hbar}|W_{fi}|^2 \int \rho(E_f)\delta(E_f - E_i)dE_f$ so

$$\boxed{R_{i\to f} = \frac{2\pi}{\hbar}|W_{fi}|^2 \rho(E_i)} \tag{13}$$

which is the so-called *Fermi's golden rule*.

## 3. Transition probability for a harmonic oscillatory perturbation

If the perturbation is time-dependent harmonic $W(t) = 2W\cos(\omega t) = W(e^{i\omega t} + e^{-i\omega t})$ when $t > 0$, Eq (8) becomes

$$\begin{aligned} c_f(t) &= \frac{W_{fi}}{i\hbar}\int_0^t \left(e^{i\omega\tau} + e^{-i\omega\tau}\right) e^{i\omega_{fi}\tau} d\tau \\ &= \frac{W_{fi}}{i\hbar}\left\{\frac{e^{i(\omega_{fi}+\omega)t} - 1}{i(\omega_{fi}+\omega)} + \frac{e^{i(\omega_{fi}-\omega)t} - 1}{i(\omega_{fi}-\omega)}\right\} \end{aligned} \tag{14}$$

Then transition probability in Eq (9) becomes

$$P_{i\to f}(t) = \frac{|W_{fi}|^2}{\hbar^2}\left\{\left(\frac{\sin((\omega_{fi}+\omega)t/2)}{(\omega_{fi}+\omega)/2}\right)^2 + \left(\frac{\sin((\omega_{fi}-\omega)t/2)}{(\omega_{fi}-\omega)/2}\right)^2\right\} \tag{15}$$

The transition rate in Eq (12) becomes

$$\boxed{\Gamma_{i\to f} = \frac{2\pi}{\hbar}|W_{fi}|^2\left[\delta(E_f - E_i + \hbar\omega) + \delta(E_f - E_i - \hbar\omega)\right]} \tag{16}$$

where the first term $E_f = E_i - \hbar\omega$ corresponds to a stimulated emission of a photon of energy $\hbar\omega$, whereas the second term $E_f = E_i + \hbar\omega$ corresponds to an absorption of a photon of energy $\hbar\omega$.[1][2][3]

## 参考

来源：https://zhuanlan.zhihu.com/p/339809311