

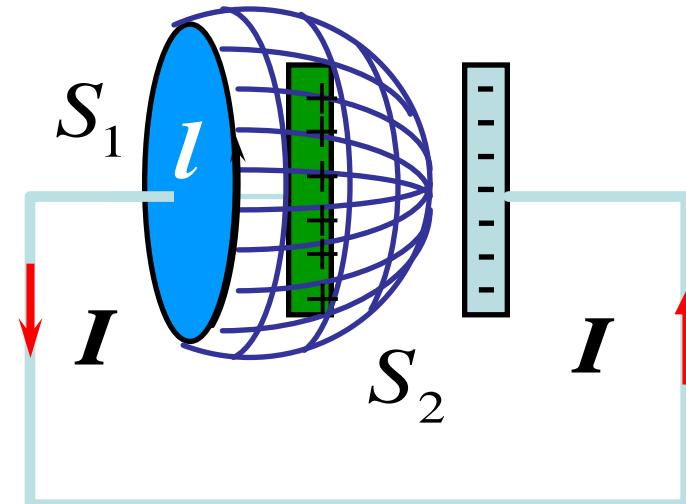
# 本节课作业

P67: 10-T18~T24

# 上节课的主要内容

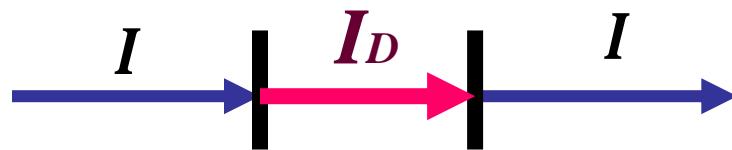
- 位移电流  $I_D = \frac{d\Phi_D}{dt} = \int \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$

$$\vec{j}_D = \frac{\partial \vec{D}}{\partial t} = \epsilon \frac{\partial \vec{E}}{\partial t}$$



- 全电流定理

传导电流 + 位移电流 = 全电流



- 麦克斯韦方程组

$$(1) \oint \vec{D} \cdot d\vec{S} = \sum q_i$$

$$(2) \oint \vec{E} \cdot d\vec{l} = - \int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{S}$$

$$(3) \oint \vec{B} \cdot d\vec{S} = 0$$

$$(4) \oint \vec{H} \cdot d\vec{l} = I + \int \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$$

# 电磁感应小结

法拉第电磁感应定律

$$\varepsilon = -\frac{d\Phi}{dt}$$

1. 动生电动势  $\varepsilon_i = \int_L \vec{E}_k \cdot d\vec{l} = \int_L (\vec{v} \times \vec{B}) \cdot d\vec{l}$

2. 感生电动势  $\varepsilon_i = \int \vec{E}_K \cdot d\vec{l} = - \int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{s}$

弛豫时间

3. 自感电动势  $\varepsilon_L = -L \frac{dI}{dt}$

$$\tau = \frac{L}{R}$$

4. 互感电动势  $\varepsilon_2 = -M \frac{di_1}{dt}$   $\varepsilon_1 = -M \frac{di_2}{dt}$

磁能  $W = \frac{1}{2} LI^2$   $W_m = \int w_m dV = \int_V \frac{1}{2} \vec{B} \cdot \vec{H} dV$

位移电流  $I_D = \int \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$

麦克斯韦方程组

## 讨论:

麦克斯韦方程并非完全对称。

$$(1) \oint \vec{D} \cdot d\vec{S} = \sum q_i$$

$$(2) \oint \vec{E} \cdot d\vec{l} = - \int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{S}$$

$$(3) \oint \vec{B} \cdot d\vec{S} = 0$$

$$(4) \oint \vec{H} \cdot d\vec{l} = I + \int \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$$

磁流  
 $I_m$  ?

磁荷  
 $q_m$  ?

磁单极存在否?

英国物理学家狄拉克(Paul Dirac)早在1931年就利用数学公式预言磁单极存在于携带磁场的管(所谓的狄拉克弦)的末端。当时他认为既然带有基本电荷的电子在宇宙中存在,那么理应带有基本“磁荷”的粒子存在,从而启发了许多物理学家开始寻找磁单极的工作。

磁单极存在与否尚无定论,找寻磁单极可以说是21世纪物理学重要的研究主题之一。

## 2. 能量存在场中

电场能  
量密度

$$w_e = \frac{1}{2} \vec{D} \cdot \vec{E}$$

## 2. 能量存在场中

磁场能  
量密度

$$w_m = \frac{1}{2} \vec{B} \cdot \vec{H}$$

电磁场的能量密度

$$w = w_e + w_m$$

$$w = \frac{1}{2} \vec{D} \cdot \vec{E} + \frac{1}{2} \vec{B} \cdot \vec{H}$$

适用于各种电场 磁场

## 九. 电磁场的物质性

实验证实：电磁场——客观存在的一种物质形态

一切物质具有基本属性：能量、质量、动量。

### 1) 电磁场能量（随时间变化的电磁场）

$$W = W_e + W_m = \int_V w dV$$

非稳恒情况下是空间和时间的函数

$$w = w_e + w_m = \frac{1}{2} \vec{D} \cdot \vec{E} + \frac{1}{2} \vec{B} \cdot \vec{H}$$

### 2) 能流密度矢量

定义：单位时间内通过与传播方向垂直的单位面积的能量. 指向能量传播的方向.

理论证明： $\vec{S} = \vec{E} \times \vec{H}$  ——又称坡印廷矢量

## 2. 电磁场质量

电磁场具有有限的运动速度 $c$ ，则其具有一定的质量 $M$ 。

由相对论质能关系： $E=Mc^2$

设单位体积中，电磁场质量为 $m$ ，能量为 $w$ ： $w=mc^2$

$$m = \frac{w}{c^2} = \frac{1}{2c^2}(\vec{D} \cdot \vec{E} + \vec{B} \cdot \vec{H}) \quad \text{——质量密度}$$

## 3. 电磁场物质性的特点

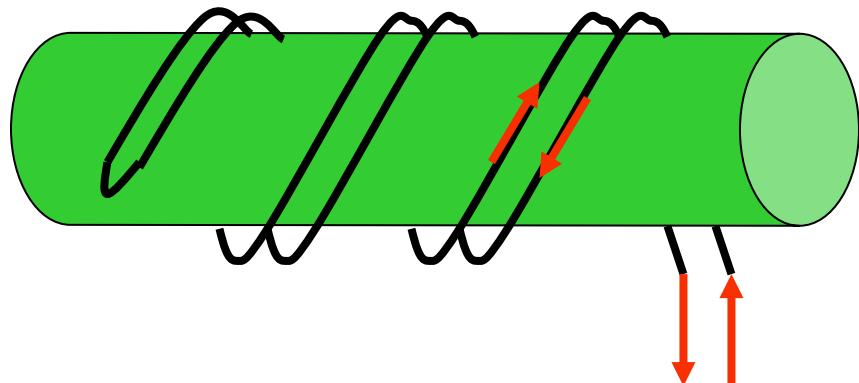
- (1) 没有静止质量： $M_0=0$       实验精度： $10^{-50}$ 左右
- (2) 电磁场以波的形式传播，  
以粒子的形式与实物相互作用；
- (3) 电磁场可相互迭加，同时占据同一空间；
- (4) 电磁波的波速与参考系无关。

**思考题1：**自感系数的公式为  $L = \frac{\phi}{I}$  能否说明通过线圈中的电流强度越小，自感系数越大？

自感系数由线圈形状尺寸等有关，与线圈中有无通电、电流强度多大等无关。

**思考题2：**用金属线绕制的标准电阻要求无自感，怎样绕制才能确保自感系数为零？

如图，双线绕制，可确保自感系数为零



$$\phi \rightarrow 0 \Rightarrow L = \frac{\phi}{I} \rightarrow 0$$

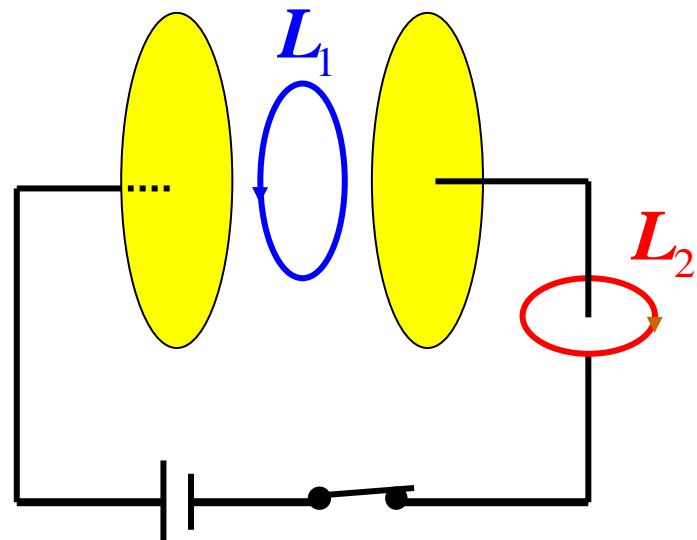
**例：**如图，平行板电容器（忽略边缘效应）充电时，沿环路 $L_1$ 、 $L_2$ 的磁场强度的环流中，正确的是（C）。

(A)  $\oint_{L_1} \vec{H} \cdot d\vec{l} > \oint_{L_2} \vec{H} \cdot d\vec{l}$

(B)  $\oint_{L_1} \vec{H} \cdot d\vec{l} = \oint_{L_2} \vec{H} \cdot d\vec{l}$

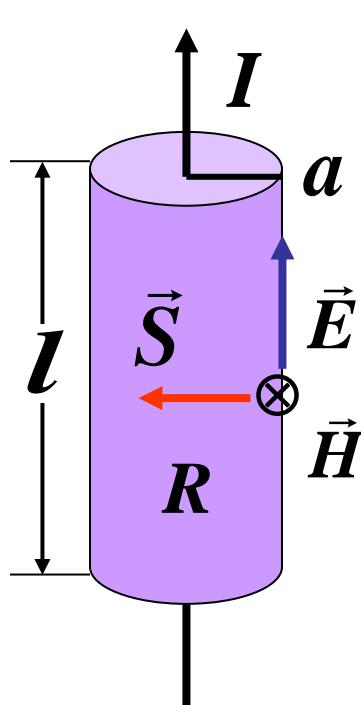
(C)  $\oint_{L_1} \vec{H} \cdot d\vec{l} < \oint_{L_2} \vec{H} \cdot d\vec{l}$

(D)  $\oint_{L_1} \vec{H} \cdot d\vec{l} = 0$



**例：**圆柱形导体，长 $l$ 半径为 $a$ ，电阻为 $R$ ，载电流 $I$ ，求证从导体侧表面输入导体的电磁能量，正好等于同时间内导体上产生的焦耳热。

**解：**单位时间从导体表面输入导体的电磁能量为



$$\begin{aligned}
 P &= \frac{dW}{dt} = - \int \vec{S} \cdot d\vec{A} \\
 &= - \int (\vec{E} \times \vec{H}) \cdot d\vec{A} \\
 &= EHA \\
 E &= \frac{V}{l} = \frac{IR}{l} \quad H = \frac{I}{2\pi a} \quad A = 2\pi a \cdot l
 \end{aligned}$$

$$\frac{dW}{dt} = \frac{IR}{l} \cdot \frac{I}{2\pi a} \cdot 2\pi a l = I^2 R \quad \text{得证。}$$

圆柱形匀强磁场中同轴放置一金属圆柱体，半径为 $R$ ，高为 $h$ ，电阻率为 $\rho$ ，如图所示。若匀强磁场以  $\frac{dB}{dt} = k$  的规律变化，求圆柱体内涡电流的热功率。

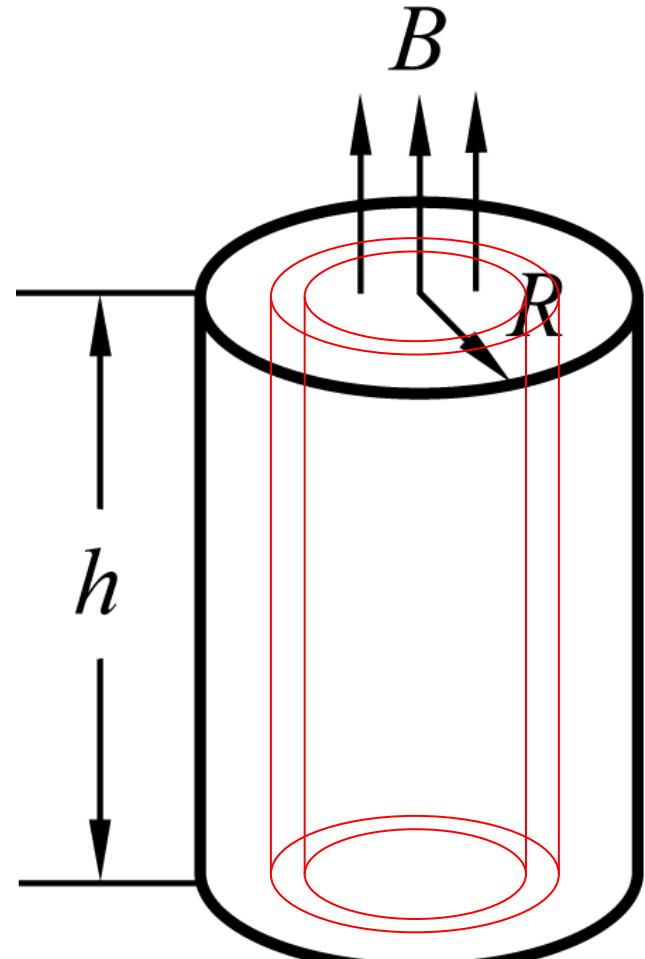
解：在圆柱体内任取一个小圆柱通

电动势 
$$\varepsilon = \frac{d\Phi}{dt} = \pi r^2 \frac{dB}{dt}$$

电阻 
$$R = \rho \frac{2\pi r}{h dr}$$

功率 
$$dP = \frac{\varepsilon^2}{R} = \frac{h}{\rho} \frac{dB}{dt} \cdot r dr$$

$$P = \int_0^R \frac{\pi h}{2\rho} \left( \frac{dB}{dt} \right)^2 \cdot r^3 dr = \frac{\pi h k^2 R^4}{8\rho}$$



2. 如图, 求  $\mathcal{E}_{CD}$ 。

解:

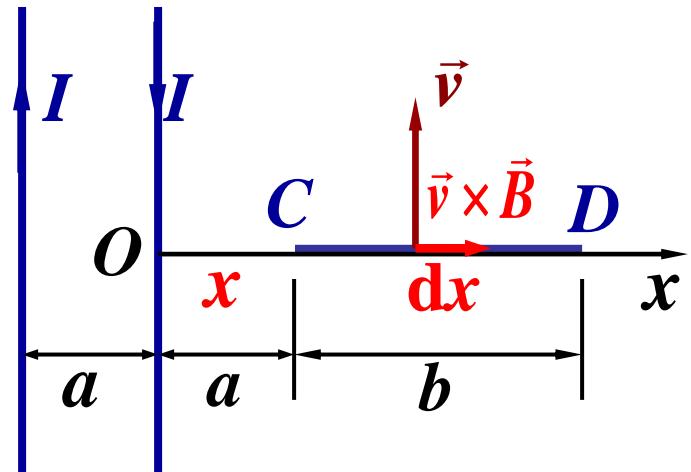
$$B = \frac{\mu_0 I}{2\pi} \left( \frac{1}{x} - \frac{1}{x+a} \right) \quad \textcircled{1}$$

$$\mathcal{E}_{CD} = \int_C^D (\vec{v} \times \vec{B}) \cdot d\vec{l}$$

$$= \int_a^{a+b} v \frac{\mu_0 I}{2\pi} \left( \frac{1}{x} - \frac{1}{x+a} \right) \sin \frac{\pi}{2} \cos 0 dx$$

$$= \frac{\mu_0 I v}{2\pi} \left( \ln \frac{a+b}{a} - \ln \frac{2a+b}{2a} \right) = \frac{\mu_0 I v}{2\pi} \ln \frac{2(a+b)}{2a+b}$$

方向:  $C \rightarrow D$ ,  $D$ 点电势高。



截面积为  $S$ , 平均周长为  $l$  的密绕螺线环, 初级绕组  $N_1$  匝, 次级绕组  $N_2$  匝。求: (1)每一线圈的自感系数; (2)两组线圈间的互感系数; (3) 自感系数与互感系数的关系。

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(1) 设线圈 1 中有电流  $I_1$ , 则环内磁感强度为:

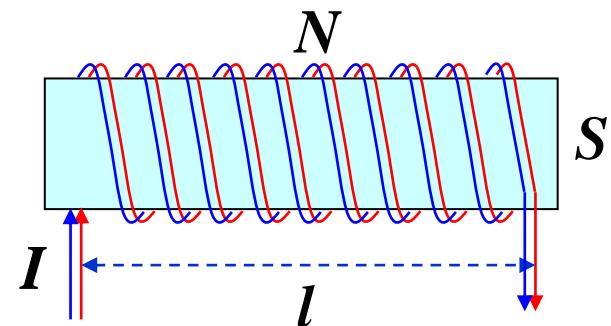
$$B_1 = \mu_0 \frac{N_1}{l} I_1$$

通过线圈 1 的磁链:

$$\Psi_1 = N_1 \Phi_1 = \mu_0 \frac{N_1^2}{l} S I_1$$

所以:

$$L_1 = \mu_0 \frac{N_1^2}{l} S = \mu_0 n_1^2 V$$

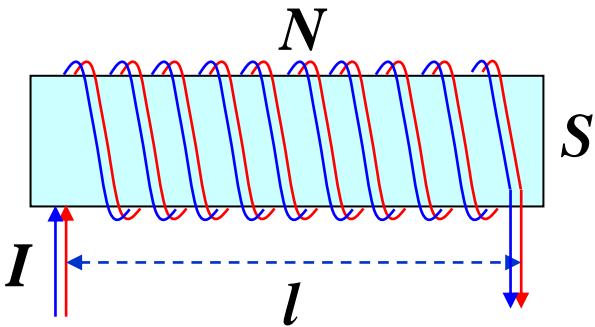


$$n = \frac{N}{l}, \quad V = lS$$

同理:  $L_2 = \mu_0 \frac{N_2^2}{l} S = \mu_0 n_2^2 V$

(2) 设线圈1中有电流 $I_1$ , 则穿过线圈2的磁链为:

$$\Psi_{21} = N_2 B_1 S = \mu_0 \frac{N_1 N_2}{l} S I_1$$



由互感的定义:

$$M = \mu_0 \frac{N_1 N_2}{l} S$$

$$L_1 = \mu_0 \frac{N_1^2}{l} S = \mu_0 n_1^2 V$$

$$L_2 = \mu_0 \frac{N_2^2}{l} S = \mu_0 n_2^2 V$$

即:

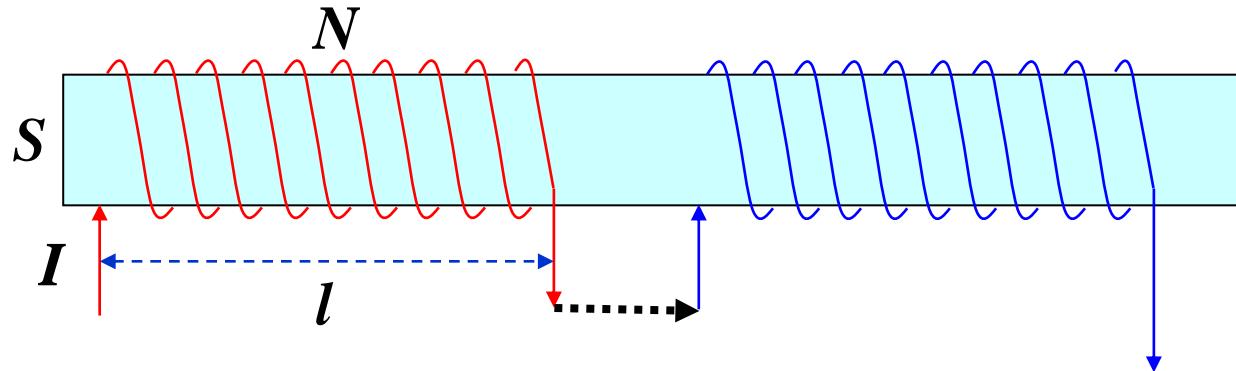
$$M = \sqrt{L_1 L_2}$$

上式为“完全耦合”的结果,一般情况下:

$$M = K \sqrt{L_1 L_2}$$

K称为两线圈的“耦合系数”。

顺串



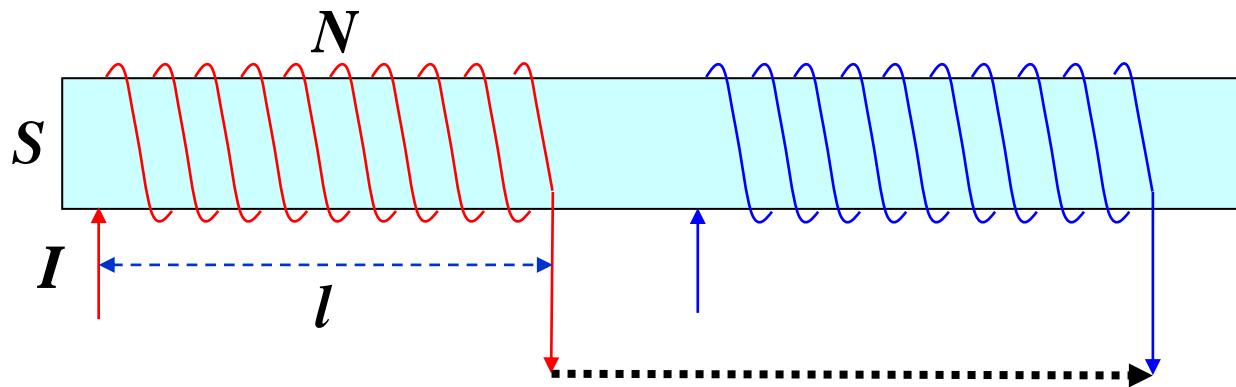
线圈1  $\mathcal{E}_1 + \mathcal{E}_{21} = -L_1 \frac{dI}{dt} - M \frac{dI}{dt}$

线圈2  $\mathcal{E}_2 + \mathcal{E}_{12} = -L_2 \frac{dI}{dt} - M \frac{dI}{dt}$

总电动势  $\mathcal{E} = \mathcal{E}_1 + \mathcal{E}_{21} + \mathcal{E}_2 + \mathcal{E}_{12} = -(L_1 + L_2) \frac{dI}{dt} - 2M \frac{dI}{dt}$

$$\mathcal{E} = -L \frac{dI}{dt} \Rightarrow L = L_1 + L_2 + 2M$$

反串



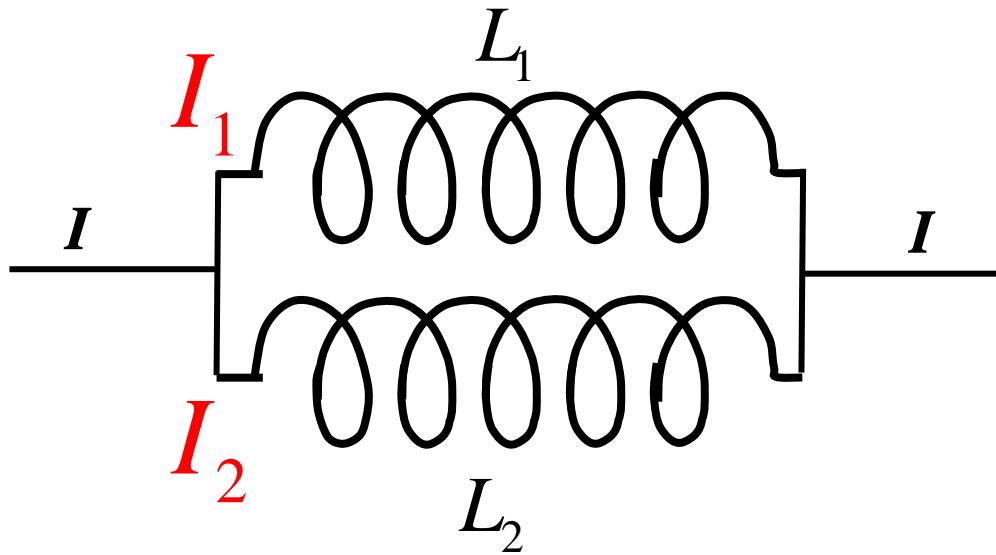
线圈1  $\mathcal{E}_1 - \mathcal{E}_{21} = -L_1 \frac{dI}{dt} + M \frac{dI}{dt}$

线圈2  $\mathcal{E}_2 - \mathcal{E}_{12} = -L_2 \frac{dI}{dt} + M \frac{dI}{dt}$

总电动势  $\mathcal{E} = \mathcal{E}_1 - \mathcal{E}_{21} + \mathcal{E}_2 - \mathcal{E}_{12} = -(L_1 + L_2) \frac{dI}{dt} + 2M \frac{dI}{dt}$

$$\mathcal{E} = -L \frac{dI}{dt} \Rightarrow L = L_1 + L_2 - 2M$$

并联



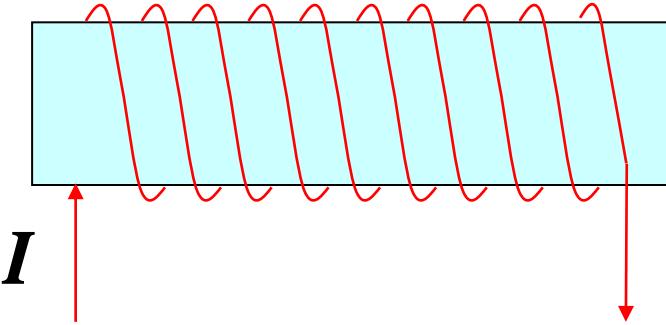
线圈1       $\varepsilon_1 = -L_1 \frac{dI_1}{dt} - M \frac{dI_2}{dt}$

线圈2       $\varepsilon_2 = -L_2 \frac{dI_2}{dt} - M \frac{dI_1}{dt}$

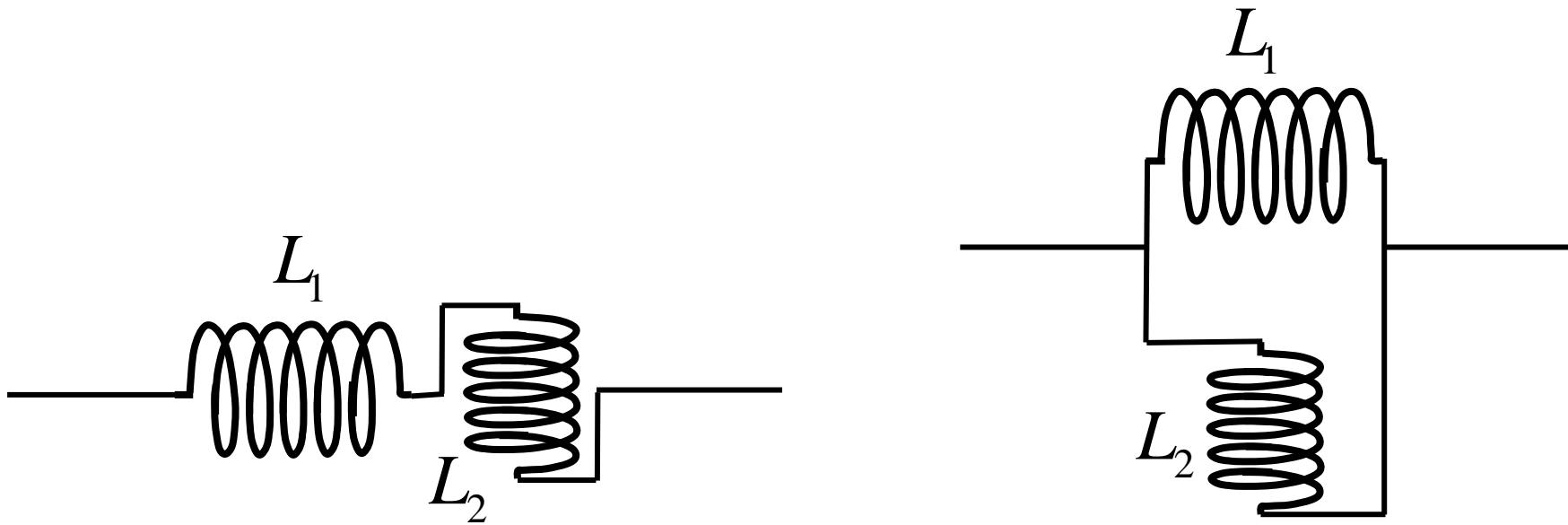
$\left. \begin{array}{l} \varepsilon_1 = \varepsilon_2 \\ I = I_1 + I_2 \end{array} \right\}$

$$\varepsilon = -L \frac{dI}{dt} \Rightarrow L = \frac{\varepsilon}{dI_1/dt + dI_2/dt} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$$

将线圈一分为二



新自感  $L'$  \_\_\_\_\_  $L/2$   
(“>”, “<”, “=”)



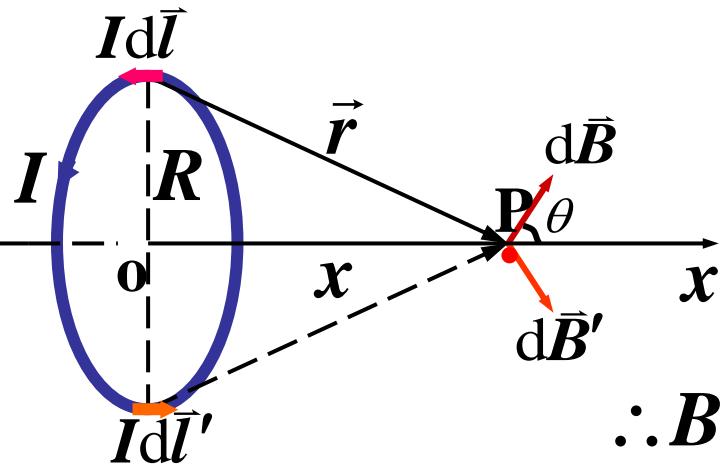
如图，具有相同轴线的两个导线回路，小的回路在大回路上面距离 $y$ 处， $y$ 远大于回路的半径 $R$ ，因此当大回路中有电流 $I$ 按图示方向流过时，小回路所围面积 $\pi r^2$ 之内的磁场几乎是均匀的。先假定 $y$ 以匀速 $v = dy/dt$ 而变化。

(1) 试确定穿过小回路的磁通量和 $y$ 之间的关系；

(2) 当 $y=NR$ 时（ $N$ 为整数），小回路内产生的感生电动势；

(3) 若 $v > 0$ ，确定小回路内感应电流的方向。

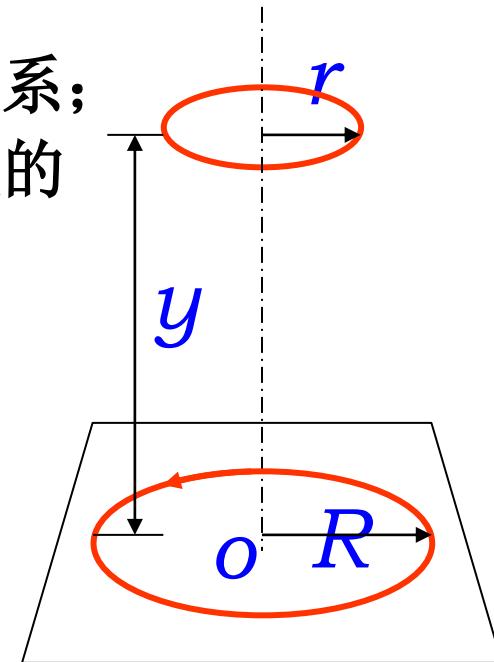
解：



$$\therefore B = \frac{\mu_0}{4\pi} \int \frac{I \cos \theta dl}{r^2} = \int_0^{2\pi R} \frac{\mu_0 IR}{4\pi(x^2 + R^2)^{3/2}} dl$$

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{Id\vec{l} \times \vec{r}}{r^3}$$

$$B = \frac{\mu_0 IR^2}{2(x^2 + R^2)^{3/2}}$$



如图，具有相同轴线的两个导线回路，小的回路在大回路上面距离 $y$ 处， $y$ 远大于回路的半径 $R$ ，因此当大回路中有电流 $I$ 按图示方向流过时，小回路所围面积 $\pi r^2$ 之内的磁场几乎是均匀的。先假定 $y$ 以匀速 $v = dy/dt$ 而变化。

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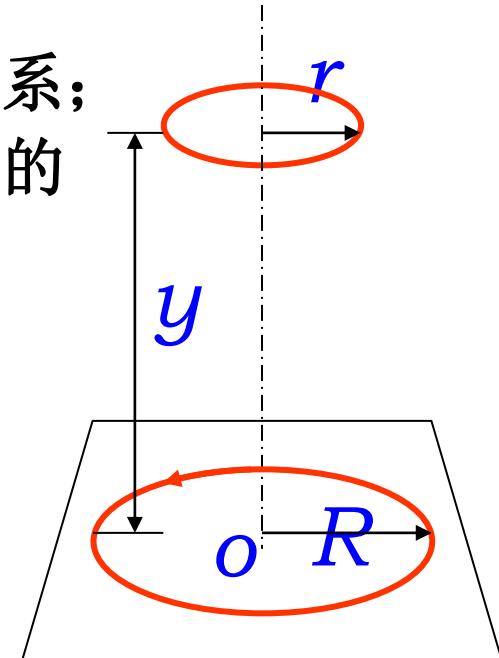
(3) 若 $v > 0$ ，确定小回路内感应电流的方向。

$$B_0 = \frac{\mu_0 I R^2}{2(R^2 + y^2)^{3/2}} \quad y \gg R \approx \frac{\mu_0 I R^2}{2y^3}$$

$$\Phi = B_0 \pi r^2 = \frac{\mu_0 I \pi r^2 R^2}{2y^3}$$

$$y = NR \quad v = \frac{dy}{dt}$$

$$\mathcal{E} = -\frac{d\Phi}{dt} = -\left(\frac{3\mu_0 I \pi r^2 R^2}{2y^4}\right) \frac{dy}{dt} = -\frac{3\mu_0 I \pi r^2}{2R^2 N^4} v$$

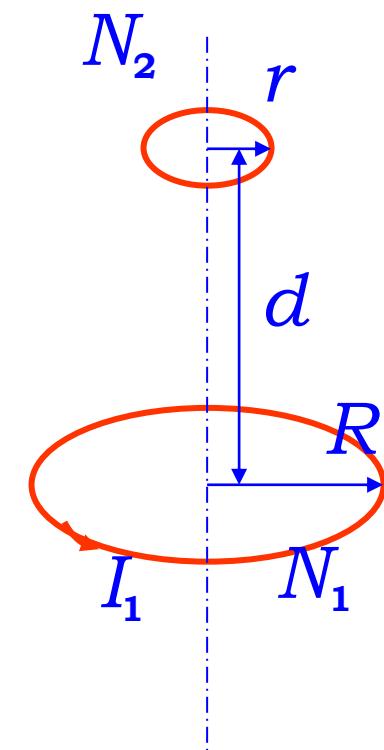


两个共轴圆线圈，半径分别为  $R$  及  $r$ ，匝数分别为  $N_1$  和  $N_2$ ，相距为  $d$ ，设  $r$  很小，则小线圈所在处的磁场可视为均匀的，求两线圈的互感系数。

解：

$$B_1 = \frac{N_1 \mu_0 I_1 \pi R^2}{2\pi(R^2 + d^2)^{3/2}}$$

$$\Psi_{21} = N_2 B_1 S = \frac{N_2 N_1 \mu_0 I_1 \pi R^2}{2\pi(R^2 + d^2)^{3/2}} \pi r^2$$



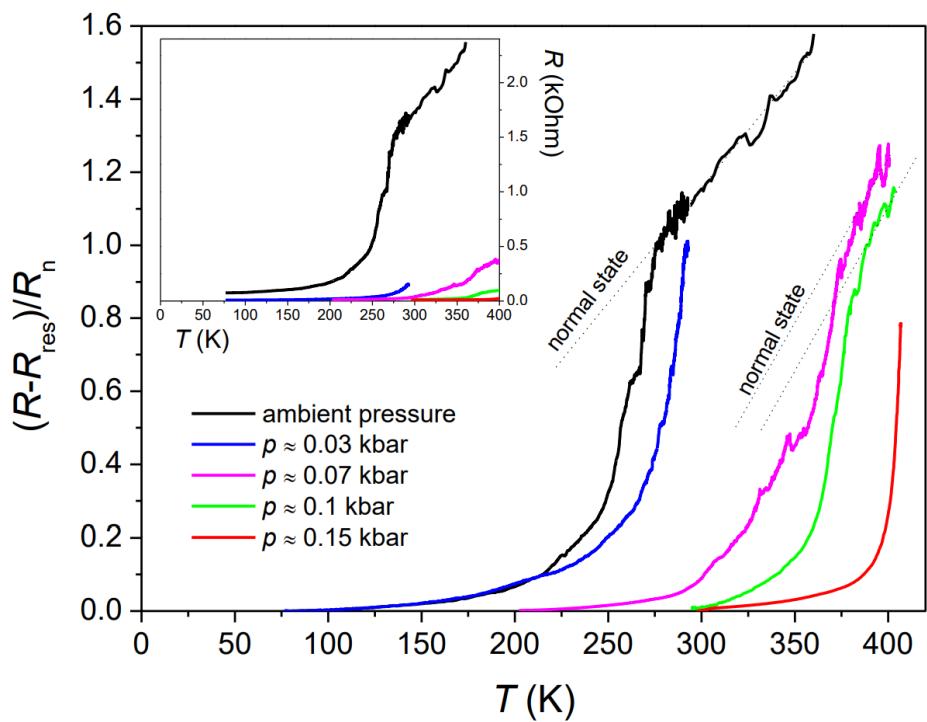
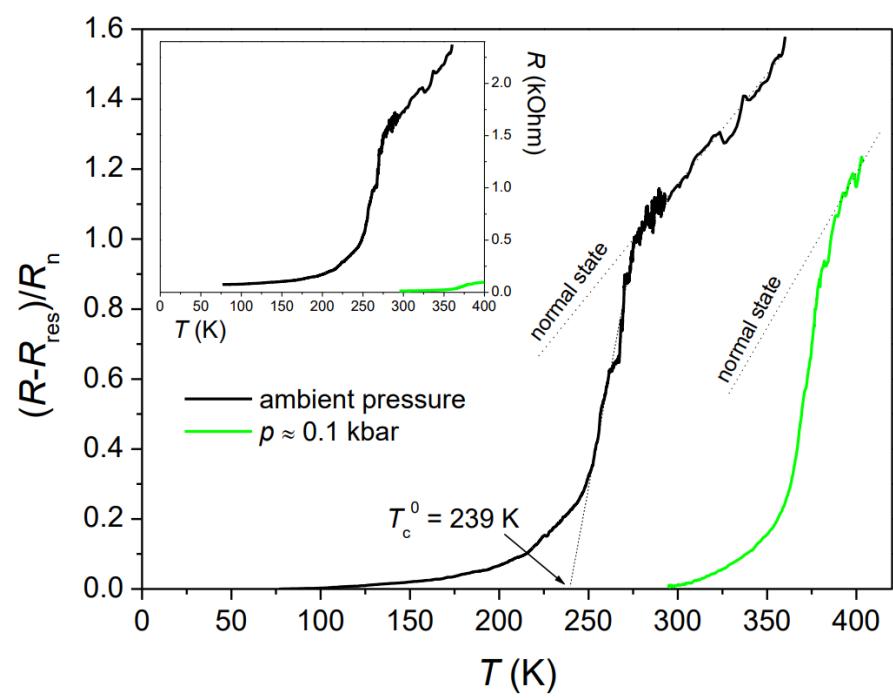
$$M = \frac{\Psi_{21}}{I_1} = \frac{\mu_0 N_2 N_1 \pi r^2 R^2}{2(R^2 + d^2)^{3/2}}$$

## Condensed Matter &gt; Superconductivity

[Submitted on 23 Sep 2025 (v1), last revised 24 Sep 2025 (this version, v2)]

# High temperature superconductivity with giant pressure effect in 3D networks of boron doped ultra-thin carbon nanotubes in the pores of ZSM-5 zeolite

Yibo Wang, Tsin Hei Koo, Runqing Huang, Yat Hei Ng, Timothée Tianyu Lortz, Ting Zhang, Wai Ming Chan, Yuxiao Hou, Jie Pan, Rolf Lortz, Ning Wang, Ping Sheng



# Superconductivity in 4 Angstrom Single-Walled Carbon Nanotubes

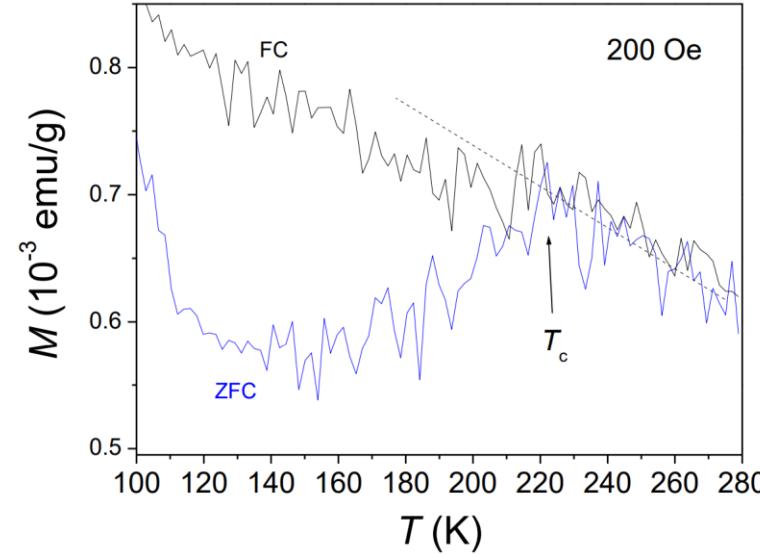
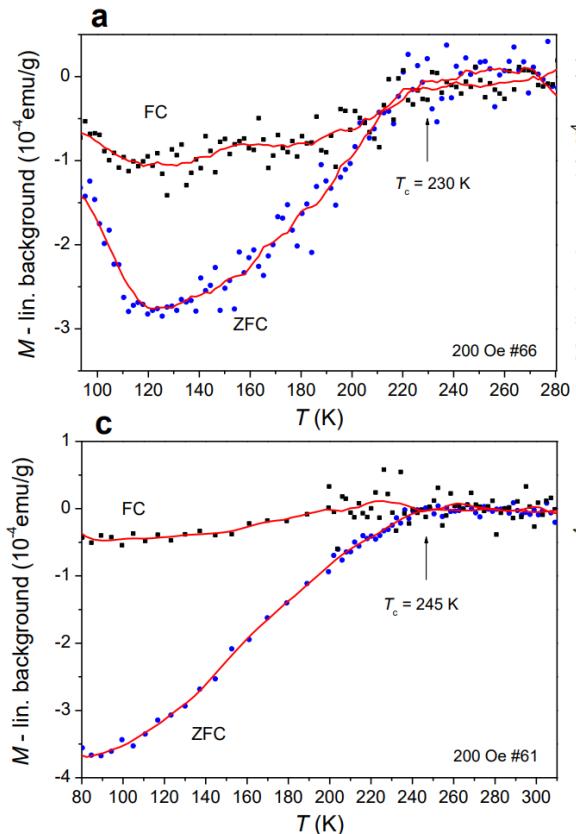
Z. K. TANG, LINGYUN ZHANG, N. WANG, X. X. ZHANG, G. H. WEN, G. D. LI, J. N. WANG, C. T. CHAN, AND PING SHENG [Authors Info & Affiliations](#)

SCIENCE • 29 Jun 2001 • Vol 292, Issue 5526 • pp. 2462-2465 • DOI: 10.1126/science.1060470

T<sub>c</sub> ~15 K

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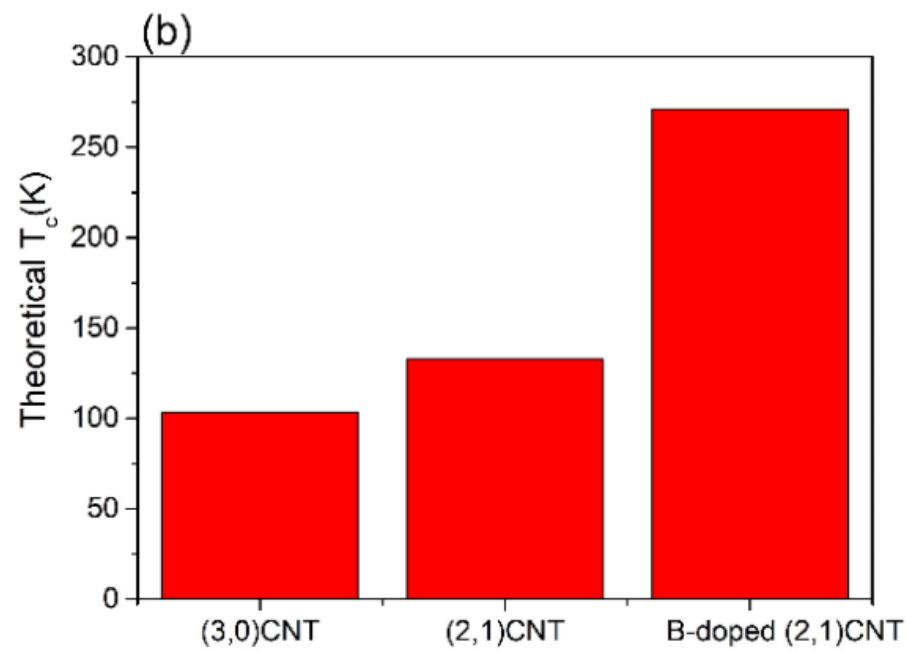
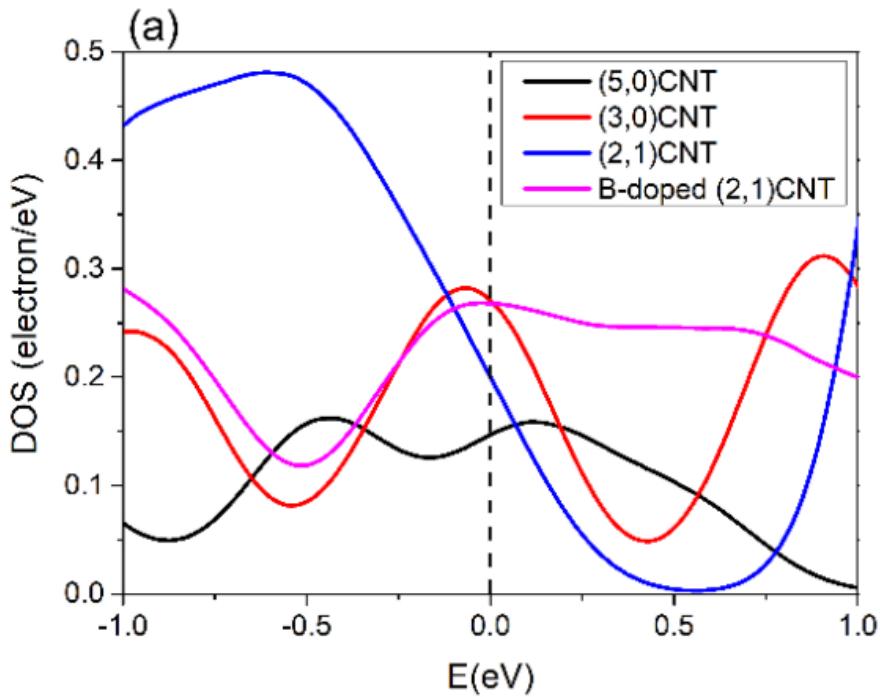
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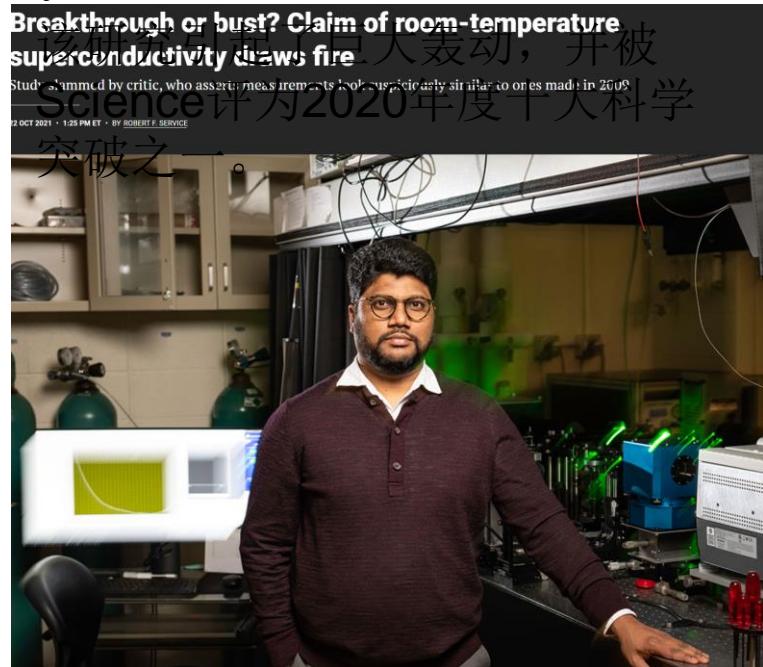
[Submitted on 25 Sep 2025]

# Room-temperature superconductivity in ultra-thin carbon nanotube zeolite composites: a conventional or unconventional superconductor?

Chi Ho Wong, Rolf Lortz



2020年，罗切斯特大学任助理教授Dias，在Nature发文声称在267 Gpa（267万个大气压）的高压下，在C-H-S的化合物中实现了近室温超导（T<sub>c</sub>= 288 K, 15 °C）。



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## RETRACTED ARTICLE: Room-temperature superconductivity in a carbonaceous sulfur hydride

[Elliot Snider](#), [Nathan Dasenbrock-Gammon](#), [Raymond McBride](#), [Mathew Debessai](#), [Hiranya Vindana](#), [Kevin Venecatasamy](#), [Keith V. Lawler](#), [Ashkan Salamat](#) & [Ranga P. Dias](#)

[Nature](#) 586, 373–377 (2020) | [Cite this article](#)

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This article was [retracted](#) on 26 September 2022

**15 February 2022** Editor's Note: The editors of Nature have been alerted to concerns regarding the manner in which the data in this paper have been processed and interpreted. Nature is

working with the authors to investigate these concerns and establish what (if any) impact they will have on the paper's results and conclusions. In the meantime, readers are advised to use caution when using results reported therein.

[Matters Arising](#) to this article was published on 25 August 2021

A [Publisher Correction](#) to this article was published on 20 November 2020

但质疑声接踵而至，例如Jorge Hirsch发现，证明近室温超导的**关键磁化率数据存在人为捏造的嫌疑**，C-S-H室温超导磁化率数据与2009年PRL一篇关于Eu超导的论文磁化率数据十分相似。

后来是Eu超导论文的其他作者在实验室一台旧电脑上，找到了测量Eu的原始数据。Eu论文的合作者Hamlin很快发现数据存在很大问题，**一些温度段的数据被直接拷贝粘贴到其他温度区间，存在严重的人为操纵证据**。Eu超导论文的其他合作者也没能重复出Eu加压超导的实验结果，很快，PRL就将Eu超导的数据撤稿了。

Hamlin发现Eu磁化率数据存在问题之后，立即联系了Dias，让Dias查看C-S-H磁化率的数据。不过Dias认为他们的文章没有问题，没有理会Hamlin的质疑，也以专利保护为由，拒绝提供原始数据。

直到PRL将Eu超导论文撤稿之后，Dias再也坐不住了，公布了C-S-H的原始数据。一经公布，Hirsch, van der Marel, Hamlin等人很快就对数据进行了仔细分析，**发现磁化率及电阻数据都存在人为操纵证据**。此外，其他课题组也没能重复出近室温超导的实验。

在强烈的质疑声浪下，Nature终于顶不住压力，不顾9位论文作者集体抗议，于2022年9月26日将其撤稿。Dias及其他作者针对撤稿并没有发表任何意见。

- ◆2023年3月，Dias再次宣称发现了室温超导，他们发现镥氮氢体系只需要1 Gpa的压强就能实现294 K的超导，在今年4月份的专利申请中，Dias团队甚至宣称镥氮氢体系在室温及常压下就有超导。这些消息瞬间引起了广泛关注，屡屡登上热搜，当然也受到很多质疑。
- ◆不到一年，文章的8位作者集体向Nature申请撤稿，终于在2023年11月7日Nature宣布将镥氮氢室温超导文章撤稿。

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## RETRACTED ARTICLE: Evidence of near-ambient superconductivity in a N-doped lutetium hydride

[Nathan Dasenbrock-Gammon](#), [Elliot Snider](#), [Raymond McBride](#), [Hiranya Pasan](#), [Dylan Durkee](#), [Nugzari Khalvashi-Sutter](#), [Sasanka Munasinghe](#), [Sachith E. Dissanayake](#), [Keith V. Lawler](#), [Ashkan Salamat](#) & [Ranga P. Dias](#)

[Nature](#) 615, 244–250 (2023) | [Cite this article](#)

120k Accesses | 155 Citations | 2199 Altmetric | [Metrics](#)

 This article was [retracted](#) on 07 November 2023

◆2017年，Dias在哈佛做博后时，宣称在495 GPa高压下实现了金属氢，相关结果发表在Science上，轰动一时。证明是金属的关键证据居然是用iPhone拍的照片，说是能看到金属光泽。据说审稿的时候，请审稿人去现场看具有金属光泽的样品。不过后来说做拉曼结构表征时，样品坏掉了，之后再也没有重复出来，其他课题组也没能重复金属氢。

### Extended Comment on *Nature* 586, 373 (2020) by E. Snider *et al.*

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#### 3.6 Coil System and AC Magnetic Susceptibility

The basic principle of the ac magnetic susceptibility measurement is shown in at the left of Figure 3.25. The sample is surrounded by a pickup coil and a separate coil subjects the sample to an alternating magnetic field. The alternating flux through the pickup coil produces an ac voltage which is the measured signal. Above  $T_c$ , the applied field penetrates the sample. When the sample is cooled below  $T_c$ , the field is expelled from the sample due to the superconducting shielding effect, forcing some of the flux lines out of the pickup coil. This leads to a reduction in the induced voltage in the pickup coil. Thus, a sudden drop in the pickup coil voltage is expected when the sample becomes superconducting.

Measuring the ac magnetic susceptibility of samples contained in a diamond anvil cell presents several difficulties. Because the coils are usually placed outside of the gasket<sup>2</sup>, the sample takes up a very small portion of the coil, in contrast to the schematic

In our susceptibility measurements, the sample is surrounded by a pickup coil, and a separate coil subjects the sample to an alternating magnetic field. The alternating flux through the pickup coil produces an AC voltage, which is the measured signal. Above the superconducting transition temperatures ( $T_c$ ), the applied field penetrates the sample. When the sample is cooled below  $T_c$ , the field is expelled from the sample due to the superconducting shielding effect, forcing some of the flux lines out of the pickup coil. This leads to a reduction in the induced voltage in the pickup coil. Thus, a sudden drop in the pickup coil voltage is expected when the sample becomes superconducting. Measuring the signal in a diamond anvil cell is challenging, because the coils are usually placed outside of the gasket, the sample takes up a very small portion of the coil. Therefore, the drop in the signal at the superconducting transition is a small fraction of the total induced voltage. To eliminate this large background voltage, we connect the pick-up coil in series with an identically wound "dummy coil", which is connected with opposite polarity, to cancel out the large background signal. The crucial point is to balance the secondary coils at room temperature so that the response from the secondary coils is as small as possible. The balancing of the coil system does not guarantee negligible temperature-dependent background, but it minimizes

the response to the lowest value possible. So, in practice, we still see a microvolt level background (temperature dependent) due to slight differences in the magnetic environments of the pick-up coil and dummy coil. [20]

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