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非对称中的对称美

——软胶磁铁磁场分布的简单探究
及 Halbach 阵列的模拟与分析

程玉银

2019/7/5

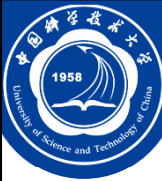


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软胶磁铁·背景与实验


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软胶磁铁(磁贴)具有“单向磁性”

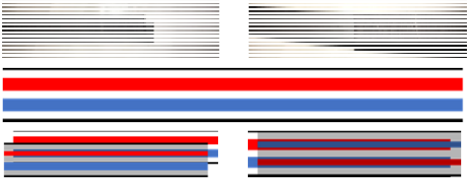
磁极性质实验：取条状软胶磁铁



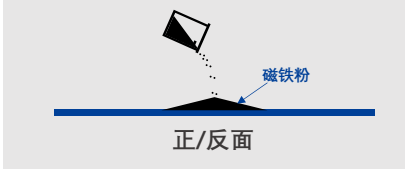
对折实验



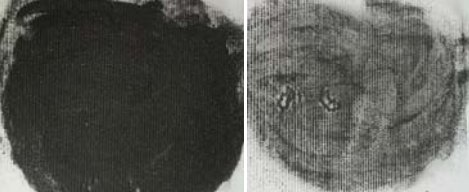
扭转实验



磁场分布实验：取片状软胶磁铁



正/反面



软胶磁铁 ● ● ○

直线阵列 ○ ○ ○

环形阵列 ○ ○ ○

磁场之美 ○ ○



软胶磁铁·实验结果


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磁场分布

强磁场

等间距、周期性旋转的阵列 Halbach阵列

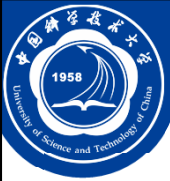


软胶磁铁 ○ ○ ●

直线阵列 ○ ○ ○

环形阵列 ○ ○ ○

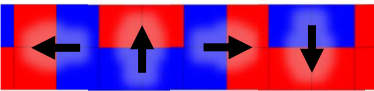
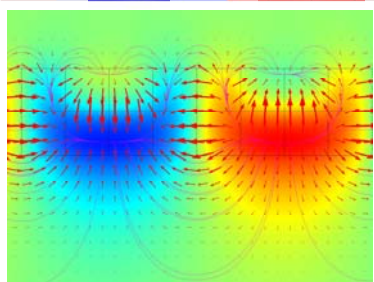
磁场之美 ○ ○



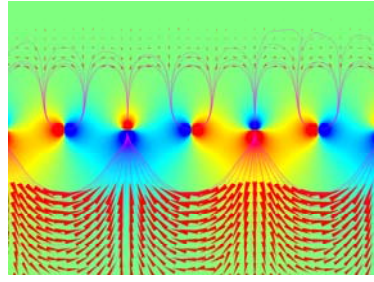
直线型阵列·算法优化

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方形电荷电场模拟

电偶极子阵列模拟



区域过大
 过于复杂
 精细不足

软胶磁铁 ○○○
直线阵列 ●○○
环形阵列 ○○○
磁场之美 ○○○



直线型阵列·最优化算法

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 2019/7/5

思路

无电流

磁荷法

“磁场，无电流”接口

边界零势

$\frac{1}{2}$ 周期

对称性

细分网格，精确计算

软胶磁铁 ○○○
直线阵列 ○●○○
环形阵列 ○○○
磁场之美 ○○○



直线型阵列·最优化算法

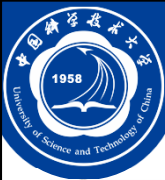
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参数

名称	表达式	值	描述
l	0.1[mm]	1E-4 m	磁偶极子两级距离的一半
a	1[cm]	0.01 m	两相邻磁偶极子中心点的距离
m	1e2	100	代表磁荷的圆环处磁标量势绝对值
n	2	2	结果绘图复制数目

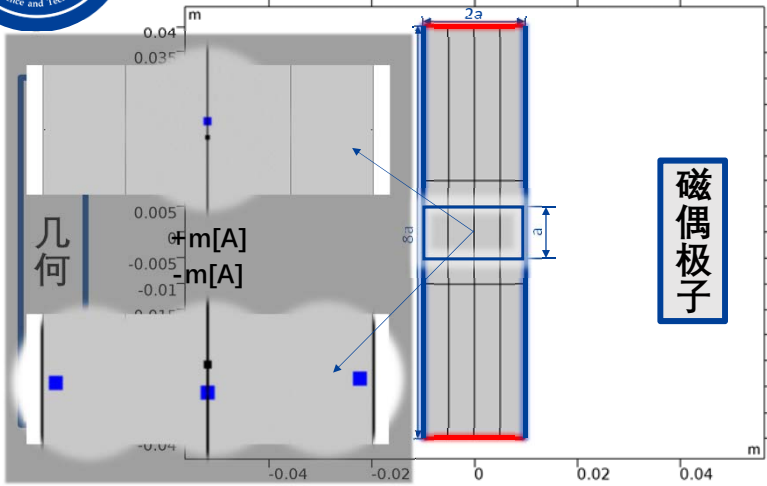
软胶磁铁
直线阵列
环形阵列
磁场之美



直线型阵列·最优化算法

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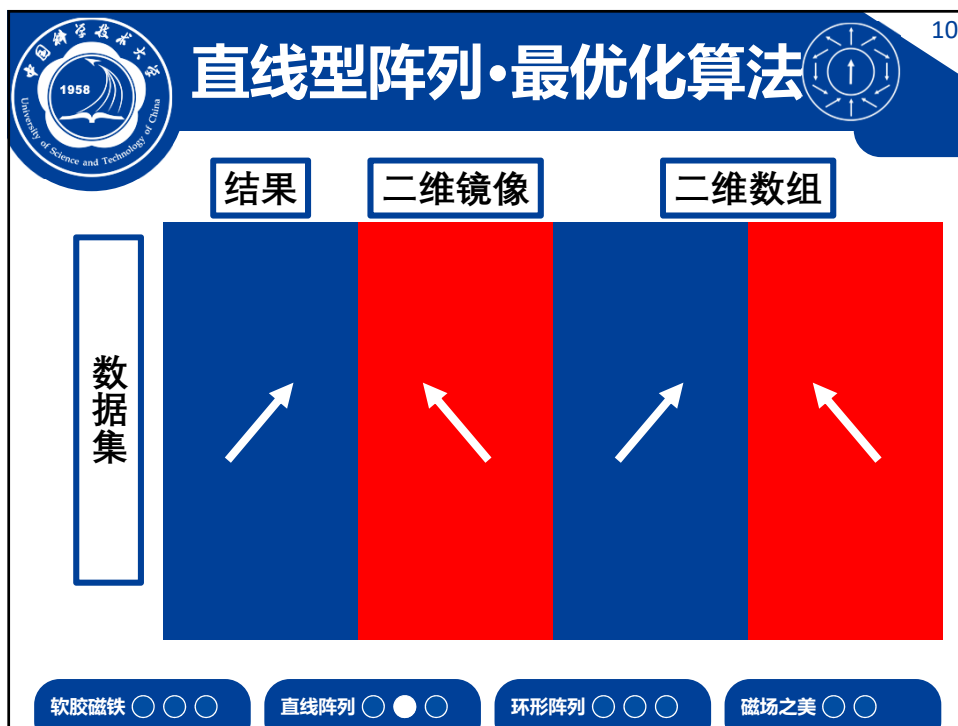
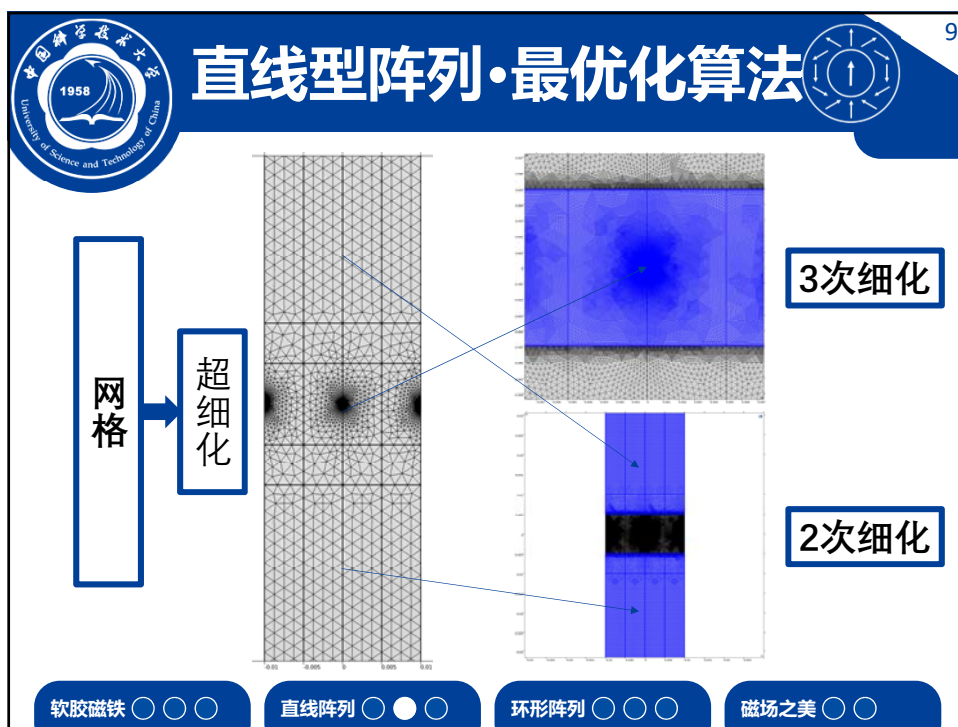


材料

零磁势

磁绝缘

软胶磁铁
直线阵列
环形阵列
磁场之美



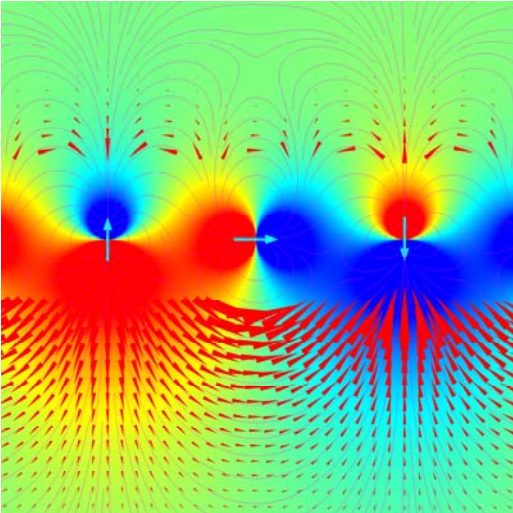
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中国科学院大学
University of Science and Technology of China
1958

直线型阵列·结果分析

结果·磁场磁标势分布



软胶磁铁

直线阵列

环形阵列

磁场之美

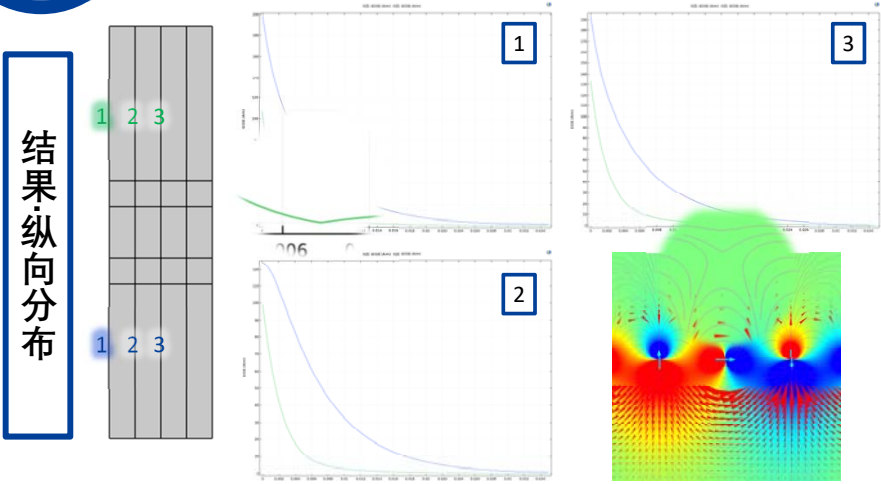
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中国科学院大学
University of Science and Technology of China
1958

直线型阵列·结果分析

结果纵向分布

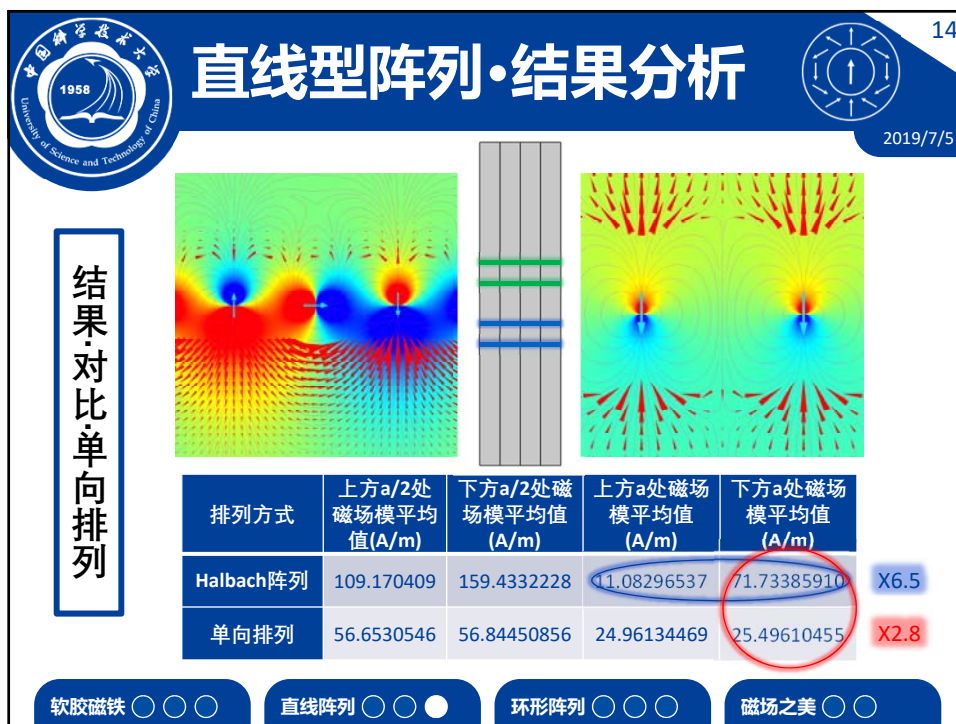
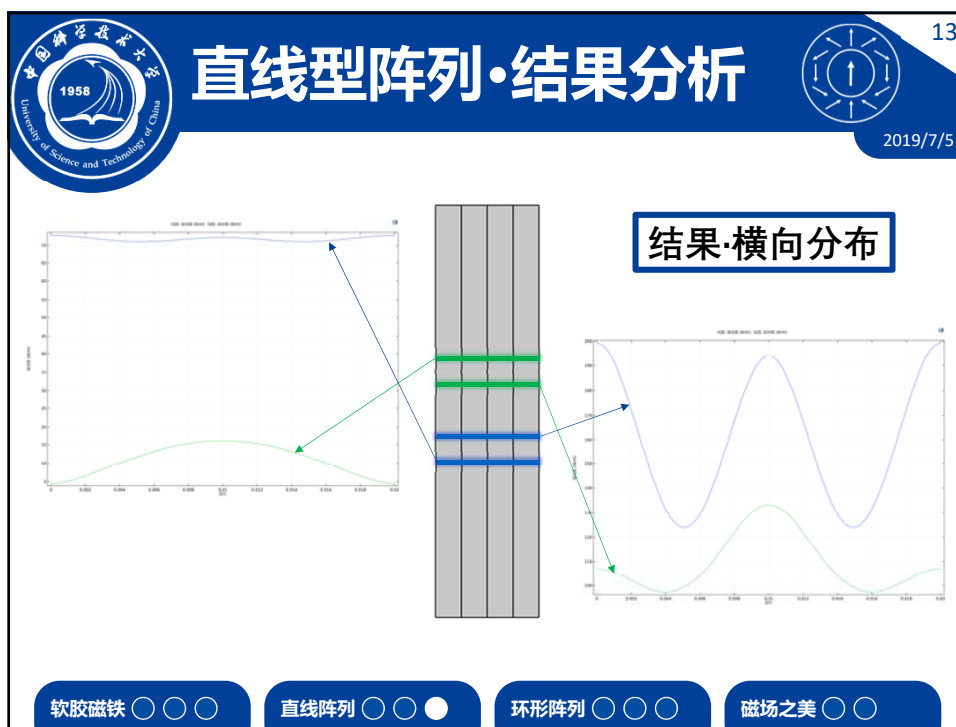


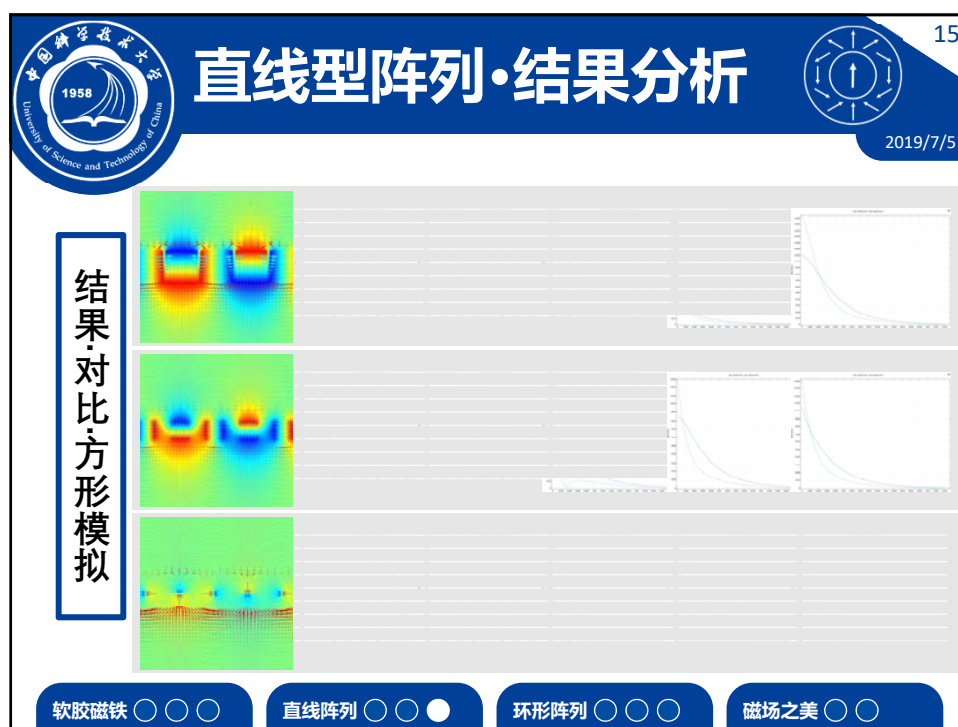
软胶磁铁

直线阵列

环形阵列

磁场之美





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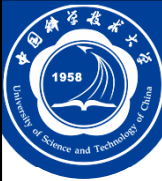
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直线型阵列·结果分析

结果对比方形模拟

边长 (mm)	上方a/2处磁场模平均值 (A/m)	下方a/2处磁场模平均值 (A/m)	上方a处磁场模平均值 B_1 (A/m)	下方a处磁场模平均值 B_2 (A/m)	B_2/B_1
9	37389.24567	17514.73624	4638.800309	7704.406963	1.66
5	12589.59503	11280.83435	2241.521349	5009.985457	2.23
1	2104.169388	2671.486502	275.6567322	1198.859809	4.34
0	109.170409	159.4332228	11.08296537	71.73385910	6.47

软胶磁铁 直线阵列 环形阵列 磁场之美



环形阵列·构成

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基础磁矩

方向 $\theta=0^\circ$

方向 $\theta=90^\circ$


旋转角: $k \cdot 30^\circ$

保证旋转周期

k表示旋转周数

逆时针为正

软胶磁铁
直线阵列
环形阵列
磁场之美




环形阵列·分类


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类别一：上下正对称，左右正对称


45° 正对称



$k=1 \quad \theta=0^\circ$

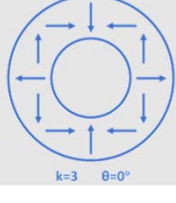


$k=5 \quad \theta=0^\circ$

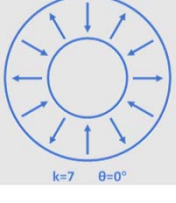


$k=9 \quad \theta=0^\circ$

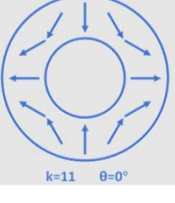
45° 反对称



$k=3 \quad \theta=0^\circ$



$k=7 \quad \theta=0^\circ$



$k=11 \quad \theta=0^\circ$

软胶磁铁
直线阵列
环形阵列
磁场之美



环形阵列·分类


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类别二：上下正对称，左右反对称



k=2 $\theta=0^\circ$



k=4 $\theta=0^\circ$



k=6 $\theta=0^\circ$



k=8 $\theta=0^\circ$



k=10 $\theta=0^\circ$



k=12 $\theta=0^\circ$

软胶磁铁

直线阵列

环形阵列

磁场之美



环形阵列·分类


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类别三：上下反对称，左右反对称

90° 反对称



k=1 $\theta=90^\circ$



k=5 $\theta=90^\circ$



k=9 $\theta=90^\circ$

90° 正对称



k=3 $\theta=90^\circ$



k=7 $\theta=90^\circ$



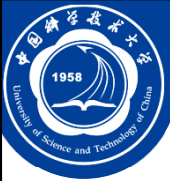
k=11 $\theta=90^\circ$

软胶磁铁


直线阵列

环形阵列

磁场之美

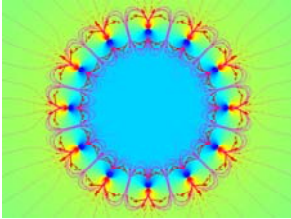
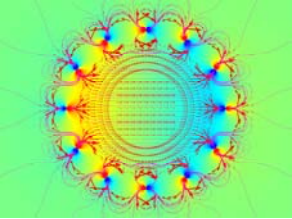
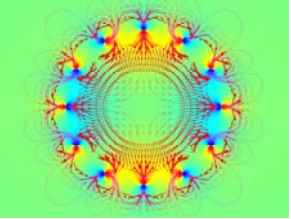
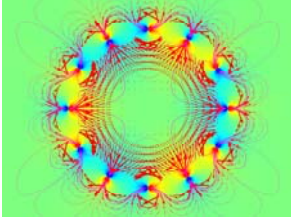
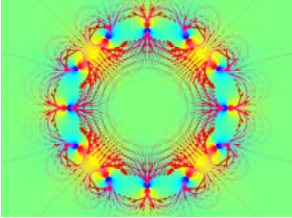
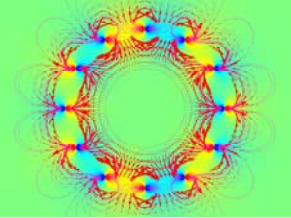


环形阵列·结果

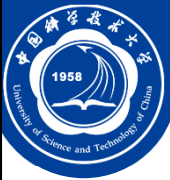
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$\theta=0^\circ, k=1\sim6$


2~5, 内大于外

软胶磁铁
直线阵列
环形阵列
磁场之美

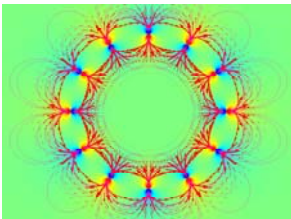
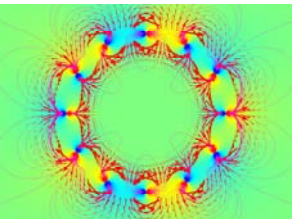
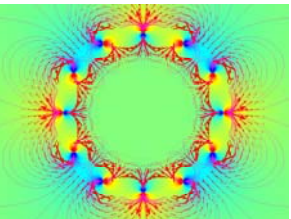
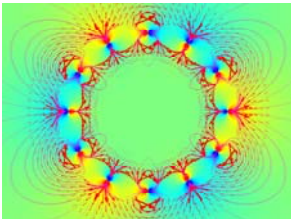
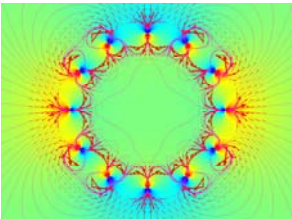
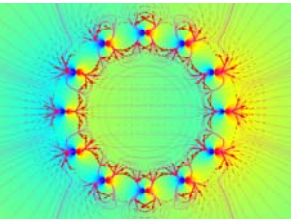


环形阵列·结果

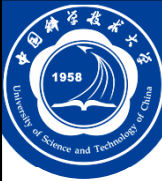
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$\theta=0^\circ, k=7\sim12$


7~11, 外大于内

软胶磁铁
直线阵列
环形阵列
磁场之美

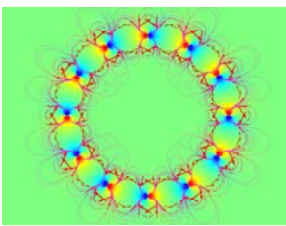
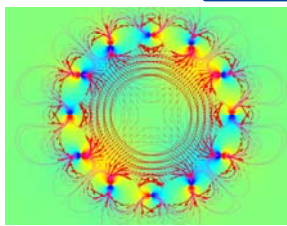
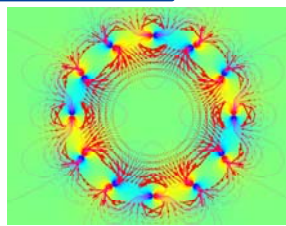


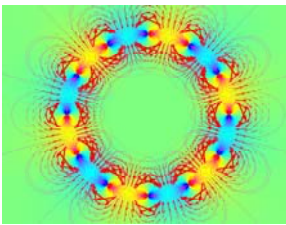
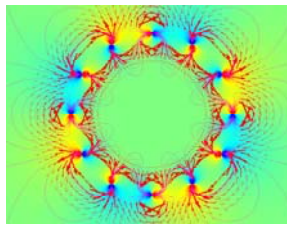
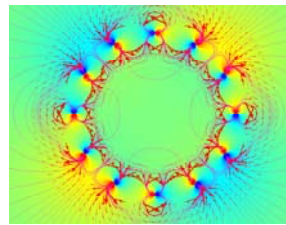
环形阵列·结果


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$\theta=90^\circ, k=1\sim 11(\text{奇})$

3、5,内大于外
7、9、11,外大于内

软胶磁铁 ○○○
直线阵列 ○○○
环形阵列 ○○●
磁场之美 ○○



磁场之美·总结


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切入:软胶磁铁

两个实验

Halbach阵列

最优化算法

方形电荷模拟

电偶极子模拟

直线型Halbach阵列

六个分布图

单向排列

方形磁体

环状Halbach阵列

构成

分类

结果

软胶磁铁 ○○○
直线阵列 ○○○
环形阵列 ○○●
磁场之美 ●○○

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2019/7/5

磁场之美·彩蛋

脸谱

太阳

花与蝶

金鱼

软胶磁铁 ○ ○ ○

直线阵列 ○ ○ ○

环形阵列 ○ ○ ○

磁场之美 ○ ●

Detailed description: This slide features four magnetic field pattern visualizations. The '脸谱' (Face) pattern shows a horizontal array of red and yellow lobes. The '太阳' (Sun) pattern is a circular, multi-lobed structure. The '花与蝶' (Flowers and Butterflies) pattern consists of two circular arrangements of lobes. The '金鱼' (Goldfish) pattern shows a horizontal array of lobes with a central dipole-like structure. A navigation bar at the bottom includes four buttons: '软胶磁铁' (Soft magnetic material), '直线阵列' (Linear array), '环形阵列' (Ring array), and '磁场之美' (Beauty of magnetic field), with the last one being selected.

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磁场之美·彩蛋

星形

菱形

匀强场

软胶磁铁 ○ ○ ○

直线阵列 ○ ○ ○

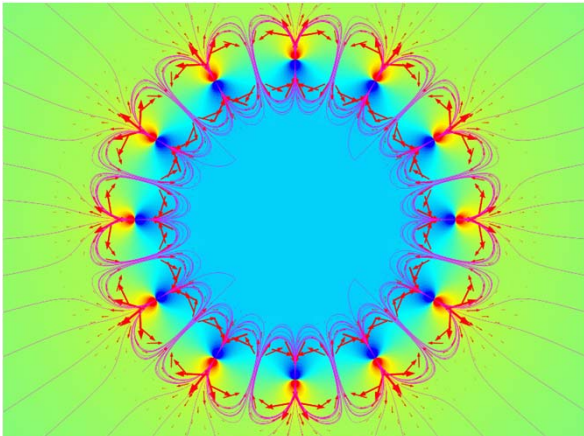
环形阵列 ○ ○ ○

磁场之美 ○ ●

Detailed description: This slide features three magnetic field pattern visualizations. The '星形' (Star) pattern is a circular arrangement of lobes with a star-like appearance. The '菱形' (Diamond) pattern is a circular arrangement of lobes with a diamond-like shape. The '匀强场' (Uniform field) pattern shows a circular arrangement of lobes with a central region of uniform field. A navigation bar at the bottom includes four buttons: '软胶磁铁' (Soft magnetic material), '直线阵列' (Linear array), '环形阵列' (Ring array), and '磁场之美' (Beauty of magnetic field), with the last one being selected.

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环状Halbach阵列

软胶磁铁 ○ ○ ○ 直线阵列 ○ ○ ○ 环形阵列 ○ ○ ○ 磁场之美 ○ ●

This slide features a blue header with the USTC logo on the left, the title "磁场之美·彩蛋" in the center, and a circular icon with an upward arrow on the right. The main content is a simulation of a circular Halbach array, showing a central blue region with a radial magnetic field pattern. Below the simulation is a label "环状Halbach阵列" in a white box. At the bottom, there is a navigation bar with four buttons: "软胶磁铁", "直线阵列", "环形阵列", and "磁场之美", each with a circle indicator.

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2019/7/5



USTC

软胶磁铁 ○ ○ ○ 直线阵列 ○ ○ ○ 环形阵列 ○ ○ ○ 磁场之美 ○ ●

This slide features a blue header with the USTC logo on the left, the title "磁场之美·彩蛋" in the center, and a circular icon with an upward arrow on the right. The main content is a simulation of the letters "USTC" formed by magnetic elements, with a colorful field pattern. Below the simulation is a label "USTC" in a white box. At the bottom, there is a navigation bar with four buttons: "软胶磁铁", "直线阵列", "环形阵列", and "磁场之美", each with a circle indicator.



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欢迎批评指正

软胶磁铁磁场分布的简单探究 及 Halbach 阵列的模拟与分析

程玉锐

2019/7/5

软胶磁铁 ○○○ 直线阵列 ○○○ 环形阵列 ○○○ 磁场之美 ○○○