

第五章 电磁波的辐射

电磁场的动量

张子珍

山西大同大学物理与电子科学学院

2013.11.10

teaching objectives

- ① 电磁场的物质性；

teaching objectives

- ① 电磁场的物质性;
- ② 动量守恒定律;

teaching objectives

- ① 电磁场的物质性；
- ② 动量守恒定律；
- ③ 动量密度与动量流密度；

teaching objectives

- ① 电磁场的物质性；
- ② 动量守恒定律；
- ③ 动量密度与动量流密度；
- ④ 辐射压力.

- ① 电磁场的物质性;
 - ② 动量守恒定律;
 - ③ 动量密度与动量流密度;
 - ④ 辐射压力.
-
- **重点:**动量守恒定律; 动量密度与动量流密度.

- ① 电磁场的物质性;
- ② 动量守恒定律;
- ③ 动量密度与动量流密度;
- ④ 辐射压力.
- **重点:**动量守恒定律; 动量密度与动量流密度.
- **难点:**动量流密度张量.

- ① 电磁场的物质性;
 - ② 动量守恒定律;
 - ③ 动量密度与动量流密度;
 - ④ 辐射压力.
-
- **重点:**动量守恒定律; 动量密度与动量流密度.
 - **难点:**动量流密度张量.

1. Materiality electromagnetic field

- 电磁场具有能量；

1. Materiality electromagnetic field

- 电磁场具有能量；
- 1900年,列别捷夫测定了光压.

1. Materiality electromagnetic field

- 电磁场具有能量；
- 1900年,列别捷夫测定了光压.

电磁场是物质,物质是运动的,电磁场和物质发生相互作用.在相互作用中,运动形式转化,转化过程中遵从两条守恒定律:

1. Materiality electromagnetic field

- 电磁场具有能量；
- 1900年,列别捷夫测定了光压.

电磁场是物质,物质是运动的,电磁场和物质发生相互作用.在相互作用中,运动形式转化,转化过程中遵从两条守恒定律:

- 能量守恒;

1. Materiality electromagnetic field

- 电磁场具有能量;
- 1900年,列别捷夫测定了光压.

电磁场是物质,物质是运动的,电磁场和物质发生相互作用.在相互作用中,运动形式转化,转化过程中遵从两条守恒定律:

- 能量守恒;动量守恒.

1. Materiality electromagnetic field

- 电磁场具有能量;
- 1900年,列别捷夫测定了光压.

电磁场是物质,物质是运动的,电磁场和物质发生相互作用.在相互作用中,运动形式转化,转化过程中遵从两条守恒定律:

- 能量守恒;动量守恒.

$$-\oint \vec{S} \cdot d\sigma = \frac{d}{dt} \int \omega dV + \int \vec{f} \cdot \vec{v} dV \quad (1)$$

1. Materiality electromagnetic field

- 电磁场具有能量;
- 1900年,列别捷夫测定了光压.

电磁场是物质,物质是运动的,电磁场和物质发生相互作用.在相互作用中,运动形式转化,转化过程中遵从两条守恒定律:

- 能量守恒;动量守恒.

$$-\oint \vec{S} \cdot d\sigma = \frac{d}{dt} \int \omega dV + \int \vec{f} \cdot \vec{v} dV \quad (1)$$

$$-\nabla \cdot \vec{S} = \frac{\partial \omega}{\partial t} + \vec{f} \cdot \vec{v} \quad (2)$$

1. Materiality electromagnetic field

- 电磁场具有能量;
- 1900年,列别捷夫测定了光压.

电磁场是物质,物质是运动的,电磁场和物质发生相互作用.在相互作用中,运动形式转化,转化过程中遵从两条守恒定律:

- 能量守恒;动量守恒.

$$-\oint \vec{S} \cdot d\sigma = \frac{d}{dt} \int \omega dV + \int \vec{f} \cdot \vec{v} dV \quad (1)$$

$$-\nabla \cdot \vec{S} = \frac{\partial \omega}{\partial t} + \vec{f} \cdot \vec{v} \quad (2)$$

2.Law of conservation of electromagnetic field momentum

$$\vec{S} = \vec{E} \times \vec{H}, \delta\omega = \vec{E} \cdot \delta\vec{D} + \vec{B} \cdot \delta\vec{H}$$

2.Law of conservation of electromagnetic field momentum

$\vec{S} = \vec{E} \times \vec{H}$, $\delta\omega = \vec{E} \cdot \delta\vec{D} + \vec{B} \cdot \delta\vec{H}$ 两个概念: 动量密度 \vec{g} , 动量流密度 $\tau, \tau^{\text{张量}}$

2.Law of conservation of electromagnetic field momentum

$\vec{S} = \vec{E} \times \vec{H}$, $\delta\omega = \vec{E} \cdot \delta\vec{D} + \vec{B} \cdot \delta\vec{H}$ 两个概念: 动量密度 \vec{g} , 动量流密度 τ , τ 张量

$$-\oint \tau \cdot d\sigma = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV \quad (3)$$

2.Law of conservation of electromagnetic field momentum

$\vec{S} = \vec{E} \times \vec{H}$, $\delta\omega = \vec{E} \cdot \delta\vec{D} + \vec{B} \cdot \delta\vec{H}$ 两个概念: 动量密度 \vec{g} , 动量流密度 τ , τ 张量

$$-\oint \tau \cdot d\sigma = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV \quad (3)$$

$$-\nabla \cdot \tau = \frac{\partial \vec{g}}{\partial t} + \vec{f} \quad (4)$$

2.Law of conservation of electromagnetic field momentum

$\vec{S} = \vec{E} \times \vec{H}$, $\delta\omega = \vec{E} \cdot \delta\vec{D} + \vec{B} \cdot \delta\vec{H}$ 两个概念: 动量密度 \vec{g} , 动量流密度 τ , τ 张量

$$-\oint \tau \cdot d\sigma = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV \quad (3)$$

$$-\nabla \cdot \tau = \frac{\partial \vec{g}}{\partial t} + \vec{f} \quad (4)$$

从 (4) 式出发推出动量密度 (矢量) 与动量流密度 (张量) 的表达式。

2.Law of conservation of electromagnetic field momentum

$\vec{S} = \vec{E} \times \vec{H}$, $\delta\omega = \vec{E} \cdot \delta\vec{D} + \vec{B} \cdot \delta\vec{H}$ 两个概念: 动量密度 \vec{g} , 动量流密度 τ , τ 张量

$$-\oint \tau \cdot d\sigma = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV \quad (3)$$

$$-\nabla \cdot \tau = \frac{\partial \vec{g}}{\partial t} + \vec{f} \quad (4)$$

从 (4) 式出发推出动量密度 (矢量) 与动量流密度 (张量) 的表达式。

3.Momentum density;Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

3.Momentum density;Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

麦克斯韦方程组

3.Momentum density;Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

麦克斯韦方程组

$$\nabla \cdot \vec{D} = \rho, \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (6)$$

3.Momentum density;Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

麦克斯韦方程组

$$\nabla \cdot \vec{D} = \rho, \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (6)$$

真空中 $\vec{D} = \epsilon_0 \vec{E}$, $\vec{B} = \mu_0 \vec{H}$, 故:

3. Momentum density; Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

麦克斯韦方程组

$$\nabla \cdot \vec{D} = \rho, \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (6)$$

真空中 $\vec{D} = \epsilon_0 \vec{E}$, $\vec{B} = \mu_0 \vec{H}$, 故:

$$\rho = \epsilon_0 \nabla \cdot \vec{E}, \vec{J} = \frac{1}{\mu_0} \nabla \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \quad (7)$$

3. Momentum density; Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

麦克斯韦方程组

$$\nabla \cdot \vec{D} = \rho, \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (6)$$

真空中 $\vec{D} = \epsilon_0 \vec{E}$, $\vec{B} = \mu_0 \vec{H}$, 故:

$$\rho = \epsilon_0 \nabla \cdot \vec{E}, \vec{J} = \frac{1}{\mu_0} \nabla \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \quad (7)$$

$$f = \epsilon_0 (\nabla \cdot \vec{E}) \vec{E} + \frac{1}{\mu_0} (\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (8)$$

3. Momentum density; Momentum flux density

$$f = \rho \vec{E} + \vec{J} \times \vec{B} \quad (5)$$

麦克斯韦方程组

$$\nabla \cdot \vec{D} = \rho, \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (6)$$

真空中 $\vec{D} = \epsilon_0 \vec{E}$, $\vec{B} = \mu_0 \vec{H}$, 故:

$$\rho = \epsilon_0 \nabla \cdot \vec{E}, \vec{J} = \frac{1}{\mu_0} \nabla \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \quad (7)$$

$$f = \epsilon_0 (\nabla \cdot \vec{E}) \vec{E} + \frac{1}{\mu_0} (\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (8)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 (\nabla \cdot \vec{E}) \vec{E} + \frac{1}{\mu_0} (\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 (\nabla \cdot \vec{E}) \vec{E} + \frac{1}{\mu_0} (\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

3.Momentum density;Momentum flux density

$$f = \epsilon_0 (\nabla \cdot \vec{E}) \vec{E} + \frac{1}{\mu_0} (\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (10)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 (\nabla \cdot \vec{E}) \vec{E} + \frac{1}{\mu_0} (\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (10)$$

电磁场是对称的

3.Momentum density;Momentum flux density

$$f = \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (10)$$

电磁场是对称的

$$f = \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \cdot \vec{B})\vec{B}$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (10)$$

电磁场是对称的

$$\begin{aligned} f &= \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \cdot \vec{B})\vec{B} \\ &\quad + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} + \epsilon_0(\nabla \times \vec{E}) \times \vec{E} \end{aligned}$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (10)$$

电磁场是对称的

$$\begin{aligned} f = & \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \cdot \vec{B})\vec{B} \\ & + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} + \epsilon_0(\nabla \times \vec{E}) \times \vec{E} \\ & - \epsilon_0(\nabla \times \vec{E}) \times \vec{E} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \end{aligned} \quad (11)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \quad (9)$$

麦克斯韦方程组

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (10)$$

电磁场是对称的

$$\begin{aligned} f = & \epsilon_0(\nabla \cdot \vec{E})\vec{E} + \frac{1}{\mu_0}(\nabla \cdot \vec{B})\vec{B} \\ & + \frac{1}{\mu_0}(\nabla \times \vec{B}) \times \vec{B} + \epsilon_0(\nabla \times \vec{E}) \times \vec{E} \\ & - \epsilon_0(\nabla \times \vec{E}) \times \vec{E} - \epsilon_0 \frac{\partial \vec{E}}{\partial t} \times \vec{B} \end{aligned} \quad (11)$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \quad (12)$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla E^2 \quad (12)$$

单位张量 σ ,对应单位矩阵,所以有

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla E^2 \quad (12)$$

单位张量 \mathcal{G} ,对应单位矩阵,所以有

$$\vec{f} \cdot \mathcal{G} = \mathcal{G} \cdot \vec{f} = \vec{f}.$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \quad (12)$$

单位张量 \mathcal{G} ,对应单位矩阵,所以有

$$\vec{f} \cdot \mathcal{G} = \mathcal{G} \cdot \vec{f} = \vec{f}.$$

$$(\nabla \cdot \vec{E}) \vec{E} + (\nabla \times \vec{E}) \times \vec{E}$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \quad (12)$$

单位张量 \mathcal{G} ,对应单位矩阵,所以有

$$\vec{f} \cdot \mathcal{G} = \mathcal{G} \cdot \vec{f} = \vec{f}.$$

$$\begin{aligned} & (\nabla \cdot \vec{E}) \vec{E} + (\nabla \times \vec{E}) \times \vec{E} \\ &= (\nabla \cdot \vec{E}) \vec{E} + (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \end{aligned}$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \quad (12)$$

单位张量 \mathcal{G} ,对应单位矩阵,所以有

$$\vec{f} \cdot \mathcal{G} = \mathcal{G} \cdot \vec{f} = \vec{f}.$$

$$\begin{aligned} & (\nabla \cdot \vec{E}) \vec{E} + (\nabla \times \vec{E}) \times \vec{E} \\ &= (\nabla \cdot \vec{E}) \vec{E} + (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \\ &= \nabla \cdot (\vec{E} \vec{E}) - \frac{1}{2} \nabla \cdot (\mathcal{G} E^2) \end{aligned}$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \quad (12)$$

单位张量 \mathcal{G} ,对应单位矩阵,所以有

$$\vec{f} \cdot \mathcal{G} = \mathcal{G} \cdot \vec{f} = \vec{f}.$$

$$\begin{aligned} & (\nabla \cdot \vec{E}) \vec{E} + (\nabla \times \vec{E}) \times \vec{E} \\ &= (\nabla \cdot \vec{E}) \vec{E} + (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \\ &= \nabla \cdot (\vec{E} \vec{E}) - \frac{1}{2} \nabla \cdot (\mathcal{G} E^2) \\ &= \nabla \cdot \left(\vec{E} \vec{E} - \frac{1}{2} \mathcal{G} E^2 \right). \end{aligned} \quad (13)$$

3.Momentum density;Momentum flux density

$$(\nabla \times \vec{E}) \times \vec{E} = (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \quad (12)$$

单位张量 \mathcal{G} ,对应单位矩阵,所以有

$$\vec{f} \cdot \mathcal{G} = \mathcal{G} \cdot \vec{f} = \vec{f}.$$

$$\begin{aligned} & (\nabla \cdot \vec{E}) \vec{E} + (\nabla \times \vec{E}) \times \vec{E} \\ &= (\nabla \cdot \vec{E}) \vec{E} + (\vec{E} \cdot \nabla) \vec{E} - \frac{1}{2} \nabla \vec{E}^2 \\ &= \nabla \cdot (\vec{E} \vec{E}) - \frac{1}{2} \nabla \cdot (\mathcal{G} E^2) \\ &= \nabla \cdot \left(\vec{E} \vec{E} - \frac{1}{2} \mathcal{G} E^2 \right). \end{aligned} \quad (13)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} \sigma E^2)$$

3. Momentum density; Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} \sigma E^2)$$

$$+ \frac{1}{\mu_0} \nabla \cdot (\vec{B} \vec{B} - \frac{1}{2} \sigma B^2)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} \sigma E^2) + \frac{1}{\mu_0} \nabla \cdot (\vec{B} \vec{B} - \frac{1}{2} \sigma B^2) - \epsilon_0 \frac{\partial(\vec{E} \times \vec{B})}{\partial t} \quad (14)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} \epsilon_0 E^2) + \frac{1}{\mu_0} \nabla \cdot (\vec{B} \vec{B} - \frac{1}{2} \mu_0 B^2) - \epsilon_0 \frac{\partial(\vec{E} \times \vec{B})}{\partial t} \quad (14)$$

比较(4)和(14),得

3.Momentum density;Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} \sigma E^2) + \frac{1}{\mu_0} \nabla \cdot (\vec{B} \vec{B} - \frac{1}{2} \sigma B^2) - \epsilon_0 \frac{\partial(\vec{E} \times \vec{B})}{\partial t} \quad (14)$$

比较(4)和(14),得

$$\tau = -\epsilon_0 \vec{E} \vec{E} - \frac{1}{\mu_0} \vec{B} \vec{B} + \frac{1}{2} \sigma \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0} \right) \quad (15)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} g E^2) + \frac{1}{\mu_0} \nabla \cdot (\vec{B} \vec{B} - \frac{1}{2} g B^2) - \epsilon_0 \frac{\partial(\vec{E} \times \vec{B})}{\partial t} \quad (14)$$

比较(4)和(14),得

$$\tau = -\epsilon_0 \vec{E} \vec{E} - \frac{1}{\mu_0} \vec{B} \vec{B} + \frac{1}{2} g \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0} \right) \quad (15)$$

$$\vec{g} = \epsilon_0 \vec{E} \times \vec{B} \quad (16)$$

3.Momentum density;Momentum flux density

$$f = \epsilon_0 \nabla \cdot (\vec{E} \vec{E} - \frac{1}{2} g E^2) + \frac{1}{\mu_0} \nabla \cdot (\vec{B} \vec{B} - \frac{1}{2} g B^2) - \epsilon_0 \frac{\partial(\vec{E} \times \vec{B})}{\partial t} \quad (14)$$

比较(4)和(14),得

$$\tau = -\epsilon_0 \vec{E} \vec{E} - \frac{1}{\mu_0} \vec{B} \vec{B} + \frac{1}{2} g \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0} \right) \quad (15)$$

$$\vec{g} = \epsilon_0 \vec{E} \times \vec{B} \quad (16)$$

3.physical interpretation of momentum flux density

$$\tau = \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \quad (17)$$

3.physical interpretation of momentum flux density

$$\tau = \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \quad (17)$$

$$d_\sigma \cdot \tau = \sum_k d_{\sigma k} \hat{e}_k \cdot \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j$$

3.physical interpretation of momentum flux density

$$\tau = \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \quad (17)$$

$$\begin{aligned} d_\sigma \cdot \tau &= \sum_k d_{\sigma k} \hat{e}_k \cdot \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \\ &= \sum_{k,i,j} d_{\sigma k} \delta_{ki} \tau_{ij} \hat{e}_j \end{aligned}$$

3.physical interpretation of momentum flux density

$$\tau = \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \quad (17)$$

$$\begin{aligned} d_\sigma \cdot \tau &= \sum_k d_{\sigma k} \hat{e}_k \cdot \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \\ &= \sum_{k,i,j} d_{\sigma k} \delta_{ki} \tau_{ij} \hat{e}_j \\ &= \sum_{i,j} d_{\sigma i} \tau_{ij} \hat{e}_j \end{aligned} \quad (18)$$

3.physical interpretation of momentum flux density

$$\tau = \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \quad (17)$$

$$\begin{aligned} d_\sigma \cdot \tau &= \sum_k d_{\sigma k} \hat{e}_k \cdot \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \\ &= \sum_{k,i,j} d_{\sigma k} \delta_{ki} \tau_{ij} \hat{e}_j \\ &= \sum_{i,j} d_{\sigma i} \tau_{ij} \hat{e}_j \end{aligned} \quad (18)$$

3. physical interpretation of momentum flux density

$$\tau = \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \quad (17)$$

$$\begin{aligned} d_\sigma \cdot \tau &= \sum_k d_{\sigma k} \hat{e}_k \cdot \sum_{i,j} \tau_{ij} \hat{e}_i \hat{e}_j \\ &= \sum_{k,i,j} d_{\sigma k} \delta_{ki} \tau_{ij} \hat{e}_j \\ &= \sum_{i,j} d_{\sigma i} \tau_{ij} \hat{e}_j \end{aligned} \quad (18)$$

物理意义：表示流过与轴垂直的面的

4. Radiation pressure

由于电磁波具有动量,它入射到物体上时会对物体施加一定的压力,这种压力称为辐射压力.

4. Radiation pressure

由于电磁波具有动量,它入射到物体上时会对物体施加一定的压力,这种压力称为辐射压力.

例:平面电磁波入射于理想导体表面上而被子全部反射,设入射角为,求导体表面所受的辐射压强.

4. Radiation pressure

由于电磁波具有动量,它入射到物体上时会对物体施加一定的压力,这种压力称为辐射压力.

例:平面电磁波入射于理想导体表面上而被子全部反射,设入射角为,求导体表面所受的辐射压强.

解:电磁波射于理想导体表面上,切线分量不变,只有垂直分量发生变化.而且变为原来的2倍.

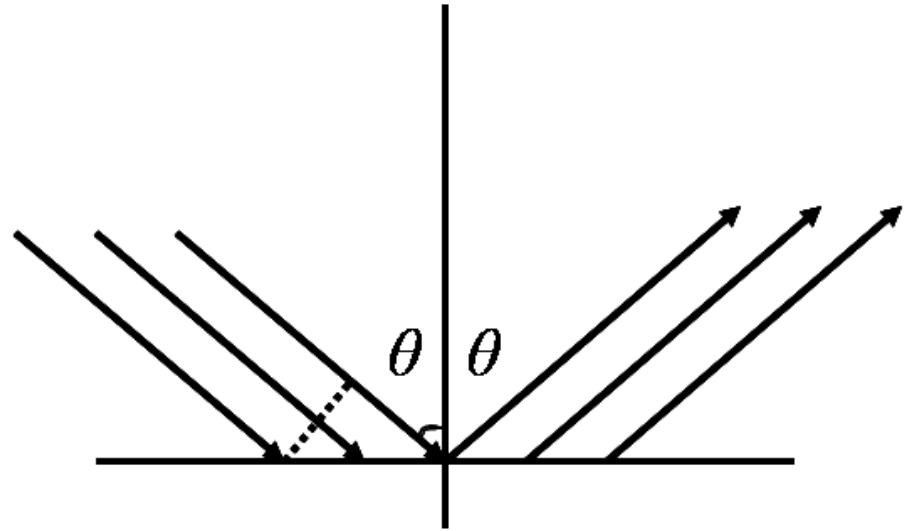
4. Radiation pressure

由于电磁波具有动量,它入射到物体上时会对物体施加一定的压力,这种压力称为辐射压力.

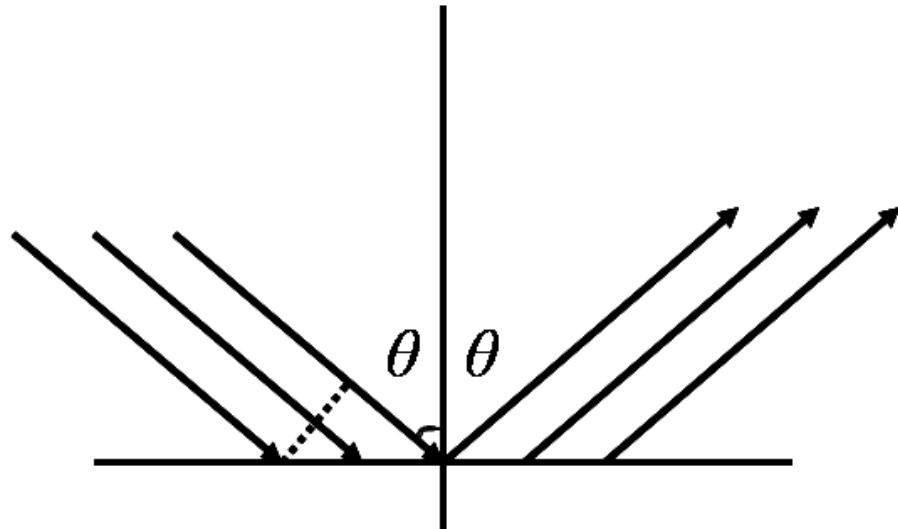
例:平面电磁波入射于理想导体表面上而被子全部反射,设入射角为,求导体表面所受的辐射压强.

解:电磁波射于理想导体表面上,切线分量不变,只有垂直分量发生变化.而且变为原来的2倍.

4. Radiation pressure

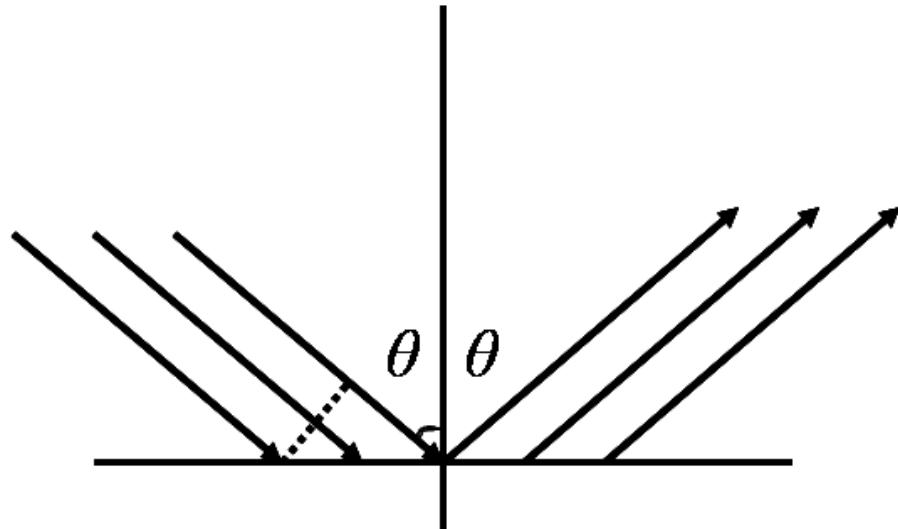


4. Radiation pressure



单位时间垂直通过单位面积的动量为：

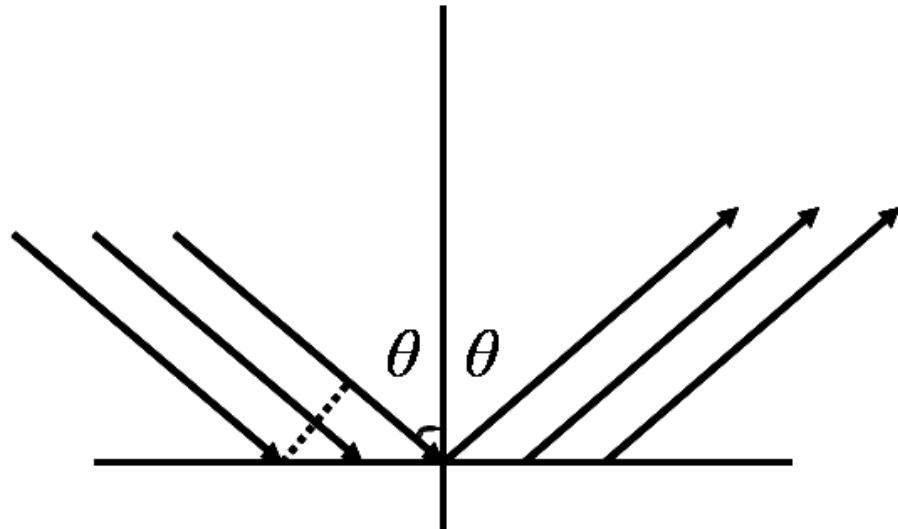
4. Radiation pressure



单位时间垂直通过单位面积的动量为：

$$\bar{g}c = \bar{\omega}; \quad (19)$$

4. Radiation pressure

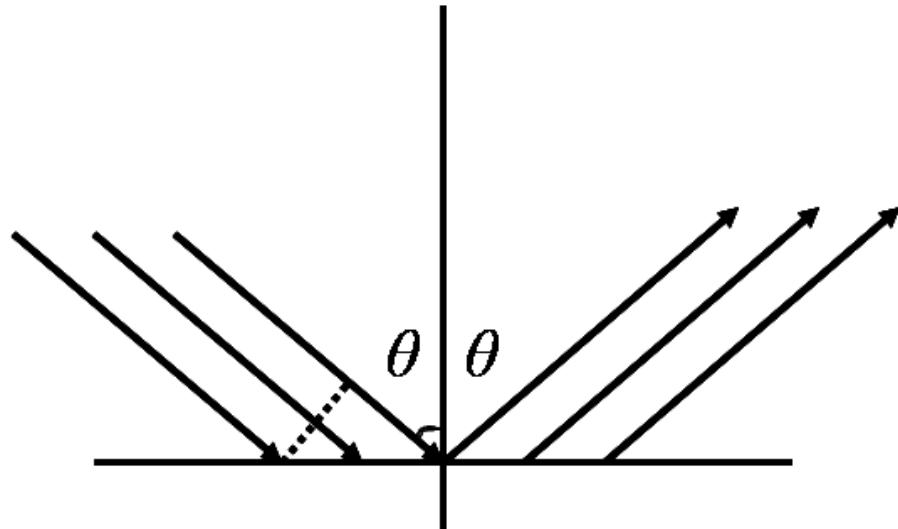


单位时间垂直通过单位面积的动量为：

$$\bar{g}c = \bar{\omega}; \quad (19)$$

单位时间垂直照射到单位面积的动量
为：

4. Radiation pressure



单位时间垂直通过单位面积的动量为：

$$\bar{g}c = \bar{\omega}; \quad (19)$$

单位时间垂直照射到单位面积的动量
为：

4. Radiation pressure

$$\bar{\omega}_i \cos \theta / \frac{1}{\cos \theta} = \bar{\omega}_i \cos^2 \theta \quad (20)$$

4. Radiation pressure

$$\bar{\omega}_i \cos \theta / \frac{1}{\cos \theta} = \bar{\omega}_i \cos^2 \theta \quad (20)$$

单位时间单位面积动量的改变量即辐射压强为：

4. Radiation pressure

$$\bar{\omega}_i \cos \theta / \frac{1}{\cos \theta} = \bar{\omega}_i \cos^2 \theta \quad (20)$$

单位时间单位面积动量的改变量即辐射压强为：

$$P = 2 \bar{\omega}_i \cos^2 \theta = \bar{\omega} \cos^2 \theta \quad (21)$$

4. Radiation pressure

$$\bar{\omega}_i \cos \theta / \frac{1}{\cos \theta} = \bar{\omega}_i \cos^2 \theta \quad (20)$$

单位时间单位面积动量的改变量即辐射压强为：

$$P = 2 \bar{\omega}_i \cos^2 \theta = \bar{\omega} \cos^2 \theta \quad (21)$$

对各方向求平均值后,得

4. Radiation pressure

$$\bar{\omega}_i \cos \theta / \frac{1}{\cos \theta} = \bar{\omega}_i \cos^2 \theta \quad (20)$$

单位时间单位面积动量的改变量即辐射压强为：

$$P = 2 \bar{\omega}_i \cos^2 \theta = \bar{\omega} \cos^2 \theta \quad (21)$$

对各方向求平均值后,得

$$P = \frac{\bar{\omega}}{3} \quad (22)$$

4. Radiation pressure

$$\bar{\omega}_i \cos \theta / \frac{1}{\cos \theta} = \bar{\omega}_i \cos^2 \theta \quad (20)$$

单位时间单位面积动量的改变量即辐射压强为：

$$P = 2 \bar{\omega}_i \cos^2 \theta = \bar{\omega} \cos^2 \theta \quad (21)$$

对各方向求平均值后,得

$$P = \frac{\bar{\omega}}{3} \quad (22)$$

电磁场的物质性

$$-\oint \boldsymbol{\tau} \cdot d\boldsymbol{\sigma} = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV$$

小结

电磁场的物质性

$$-\oint \boldsymbol{\tau} \cdot d\boldsymbol{\sigma} = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV$$

$$-\nabla \cdot \boldsymbol{\tau} = \frac{\partial \vec{g}}{\partial t} + \vec{f}$$

小结

电磁场的物质性

$$-\oint \boldsymbol{\tau} \cdot d\boldsymbol{\sigma} = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV$$

$$-\nabla \cdot \boldsymbol{\tau} = \frac{\partial \vec{g}}{\partial t} + \vec{f}$$

$$\boldsymbol{\tau} = -\epsilon_0 \vec{E} \vec{E} - \frac{1}{\mu_0} \vec{B} \vec{B} + \frac{1}{2} g \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0} \right)$$

小结

电磁场的物质性

$$-\oint \boldsymbol{\tau} \cdot d\boldsymbol{\sigma} = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV$$

$$-\nabla \cdot \boldsymbol{\tau} = \frac{\partial \vec{g}}{\partial t} + \vec{f}$$

$$\boldsymbol{\tau} = -\epsilon_0 \vec{E} \vec{E} - \frac{1}{\mu_0} \vec{B} \vec{B} + \frac{1}{2} \mathcal{G} \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0} \right)$$

$$\vec{g} = \epsilon_0 \vec{E} \times \vec{B}$$

小结

电磁场的物质性

$$-\oint \boldsymbol{\tau} \cdot d\boldsymbol{\sigma} = \frac{d}{dt} \int \vec{g} dV + \int \vec{f} dV$$

$$-\nabla \cdot \boldsymbol{\tau} = \frac{\partial \vec{g}}{\partial t} + \vec{f}$$

$$\boldsymbol{\tau} = -\epsilon_0 \vec{E} \vec{E} - \frac{1}{\mu_0} \vec{B} \vec{B} + \frac{1}{2} \mathcal{G} \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0} \right)$$

$$\vec{g} = \epsilon_0 \vec{E} \times \vec{B}$$