# Silová pole
# Gravitační pole

Síla

- při přímém styku
- prostřednictvím silového pole – gravitační, elektrické, magnetické,…

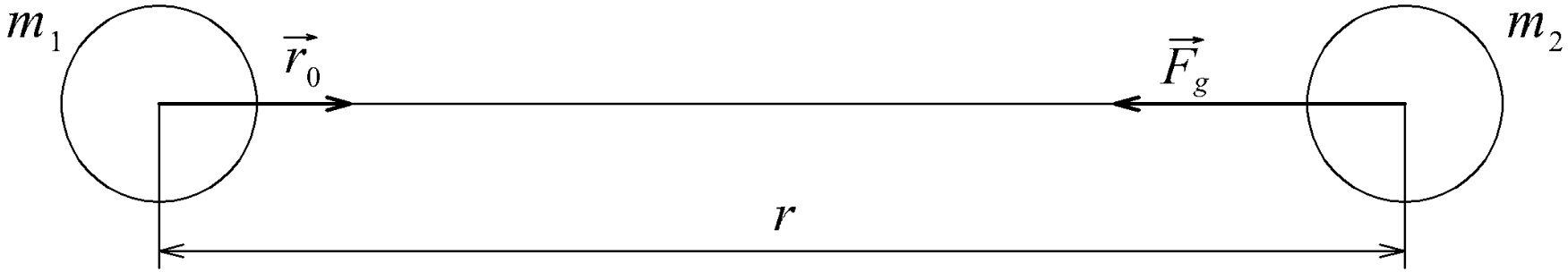
Fundamentální síly

- gravitační
- elektromagnetická
- slabá interakce

} elektroslabá interakce

- silná interakce

# Gravitační pole




Newtonův gravitační zákon

$$\vec{F}_g = -\kappa \frac{m_1 m_2}{r^2} \vec{r}_0$$

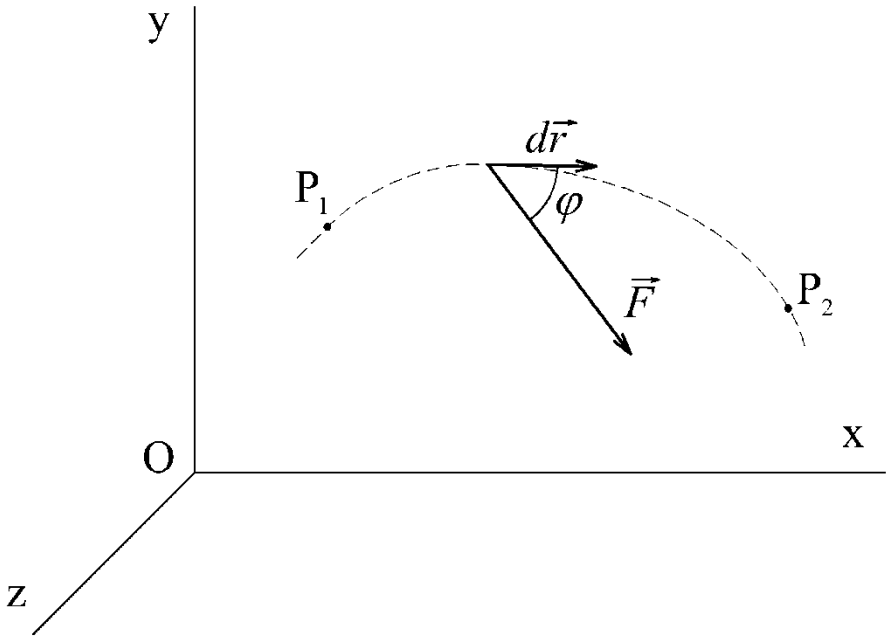
$$\kappa = 6{,}67 \cdot 10^{-11}\ \mathrm{N \cdot m^2 \cdot kg^{-2}}$$

intenzita gravitačního pole $\vec{K} = \dfrac{\vec{F}_g}{m}$

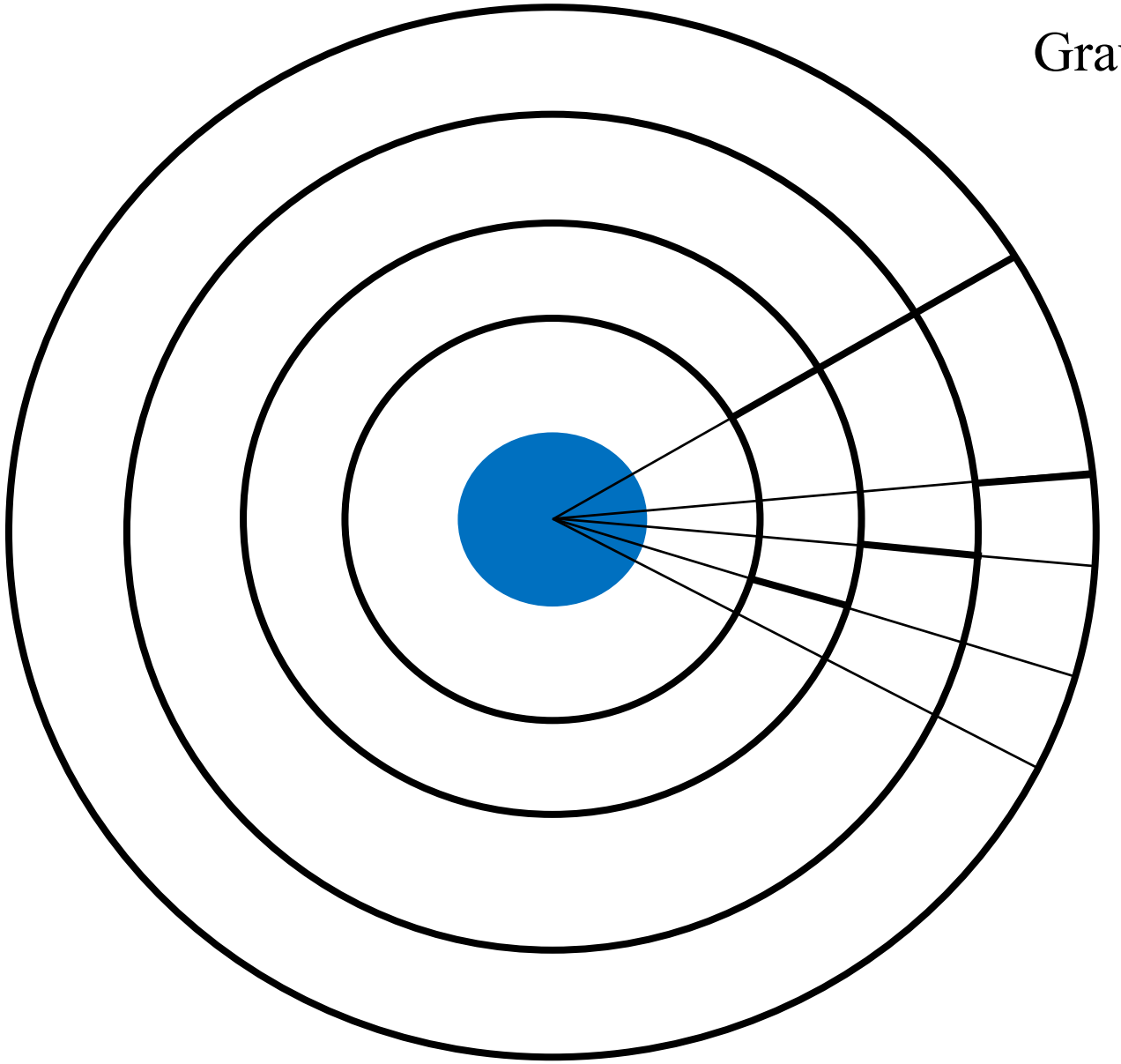
# Práce

$$dA = \vec{F} \cdot d\vec{r}$$

$$A = \int_{P_1}^{P_2} \vec{F} \cdot d\vec{r} = \int_{P_1}^{P_2} F\, dr \cos\varphi$$

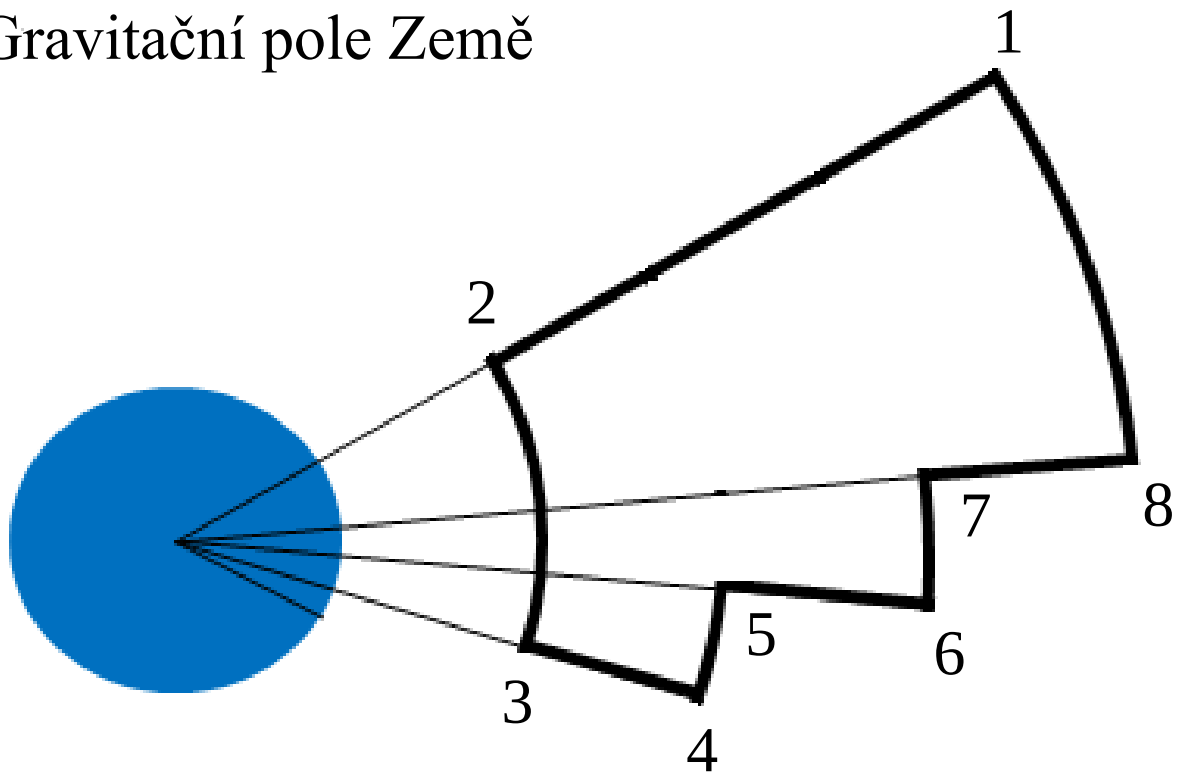


# Gravitační pole Země



# Gravitační pole Země

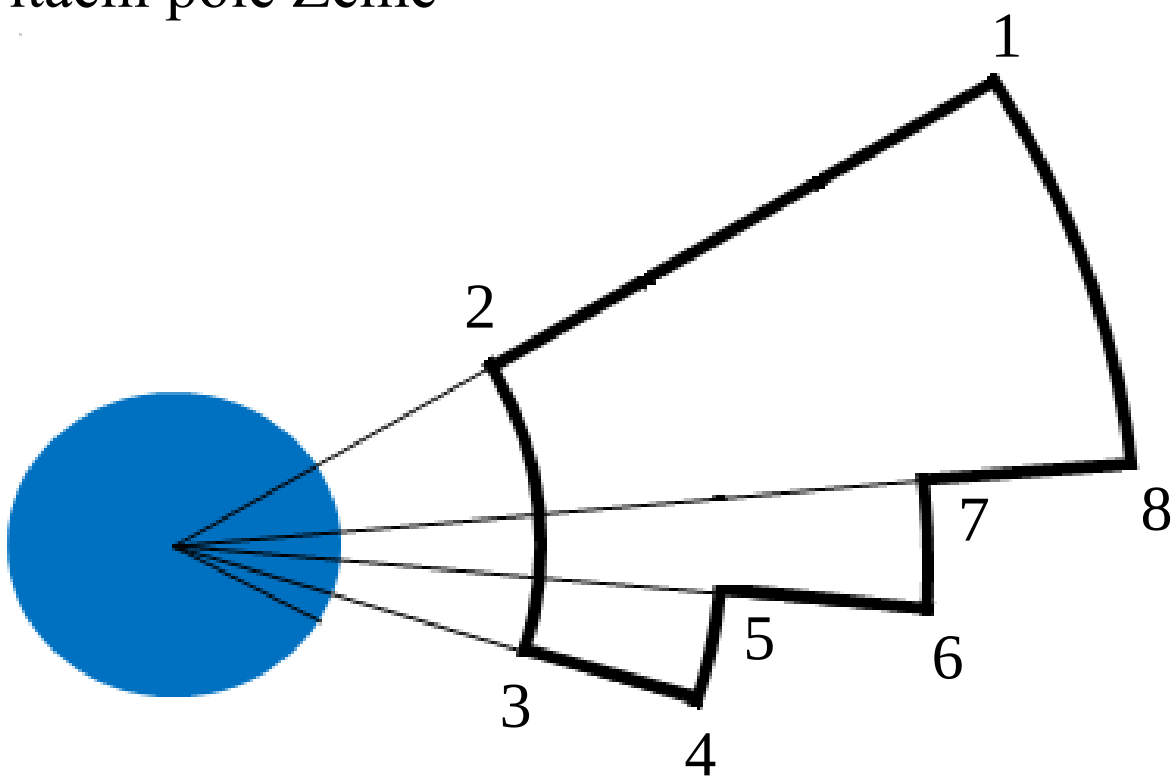
$$\vec{F} = -\kappa \frac{M_Z\, m}{r^2}\, \vec{r}_0$$




$$\oint \vec{F}\cdot d\vec{l} = \int_1^2 \vec{F}\cdot d\vec{l} + \int_2^3 \vec{F}\cdot d\vec{l} + \int_3^4 \vec{F}\cdot d\vec{l} + \int_4^5 \vec{F}\cdot d\vec{l} + \int_5^6 \vec{F}\cdot d\vec{l} + \int_6^7 \vec{F}\cdot d\vec{l} + \int_7^8 \vec{F}\cdot d\vec{l} + \int_8^1 \vec{F}\cdot d\vec{l}$$

$$\int_2^3 \vec{F}\cdot d\vec{l} = \int_4^5 \vec{F}\cdot d\vec{l} = \int_6^7 \vec{F}\cdot d\vec{l} = \int_8^1 \vec{F}\cdot d\vec{l} = 0$$

# Gravitační pole Země




$$\oint \vec{F} \cdot d\vec{l} = \int_1^2 \vec{F} \cdot d\vec{l} + \int_3^4 \vec{F} \cdot d\vec{l} + \int_5^6 \vec{F} \cdot d\vec{l} + \int_7^8 \vec{F} \cdot d\vec{l} =$$

$$= -\kappa\, M_Z\, m \int_1^2 \frac{1}{r^2} dr - \kappa\, M_Z\, m \int_3^4 \frac{1}{r^2} dr - \kappa\, M_Z\, m \int_5^6 \frac{1}{r^2} dr - \kappa\, M_Z\, m \int_7^8 \frac{1}{r^2} dr$$

$$\oint \vec{F}\cdot d\vec{l} = \int_1^2 \vec{F}\cdot d\vec{l} + \int_3^4 \vec{F}\cdot d\vec{l} + \int_5^6 \vec{F}\cdot d\vec{l} + \int_7^8 \vec{F}\cdot d\vec{l} =$$

$$= -\kappa\, M_Z\, m \int_1^2 \frac{1}{r^2} dr - \kappa\, M_Z\, m \int_3^4 \frac{1}{r^2} dr - \kappa\, M_Z\, m \int_5^6 \frac{1}{r^2} dr - \kappa\, M_Z\, m \int_7^8 \frac{1}{r^2} dr$$

$$= -\kappa\, M_Z\, m \left[ \left( -\frac{1}{r_2} + \frac{1}{r_1} \right) + \left( -\frac{1}{r_4} + \frac{1}{r_3} \right) + \left( -\frac{1}{r_6} + \frac{1}{r_5} \right) + \left( -\frac{1}{r_8} + \frac{1}{r_7} \right) \right] = 0$$

$r_2 = r_3$

$r_4 = r_5$

$r_6 = r_7$

$r_8 = r_1$

$$\oint_l \vec{F}\cdot d\vec{l} = \oint_l \vec{F}\cdot d\vec{r} = 0$$

pole konzervativní síly

- **stacionární**
- **potenciálové**

# Potenciální energie

$$\Delta W_p = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F}' \cdot d\vec{r} = -\int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r} \qquad W_p = -\int \vec{F} \cdot d\vec{r}$$

potenciál gravitačního pole $\qquad U = \frac{W_p}{m}$

$$\vec{K} = -\text{grad}\, U = \left( -\frac{\partial U}{\partial x}; -\frac{\partial U}{\partial y}; -\frac{\partial U}{\partial z} \right)$$

$$\vec{F}_g = -\text{grad}\, W_p = \left( -\frac{\partial W_p}{\partial x}; -\frac{\partial W_p}{\partial y}; -\frac{\partial W_p}{\partial z} \right)$$

# Potenciální energie gravitačního pole Země

$$\Delta W_p = -\int_{R_z}^{R_z+h} \vec{F} \cdot d\vec{r} = \kappa m M_z \int_{R_Z}^{R_Z+h} \frac{1}{r^2} dr = \kappa m M_Z \left[ -\frac{1}{r} \right]_{R_Z}^{R_Z+h}$$

$$W_p = -\kappa \frac{m M_Z}{r}$$

$$U = -\kappa \frac{M_Z}{r}$$

# Potenciální energie gravitačního pole Země

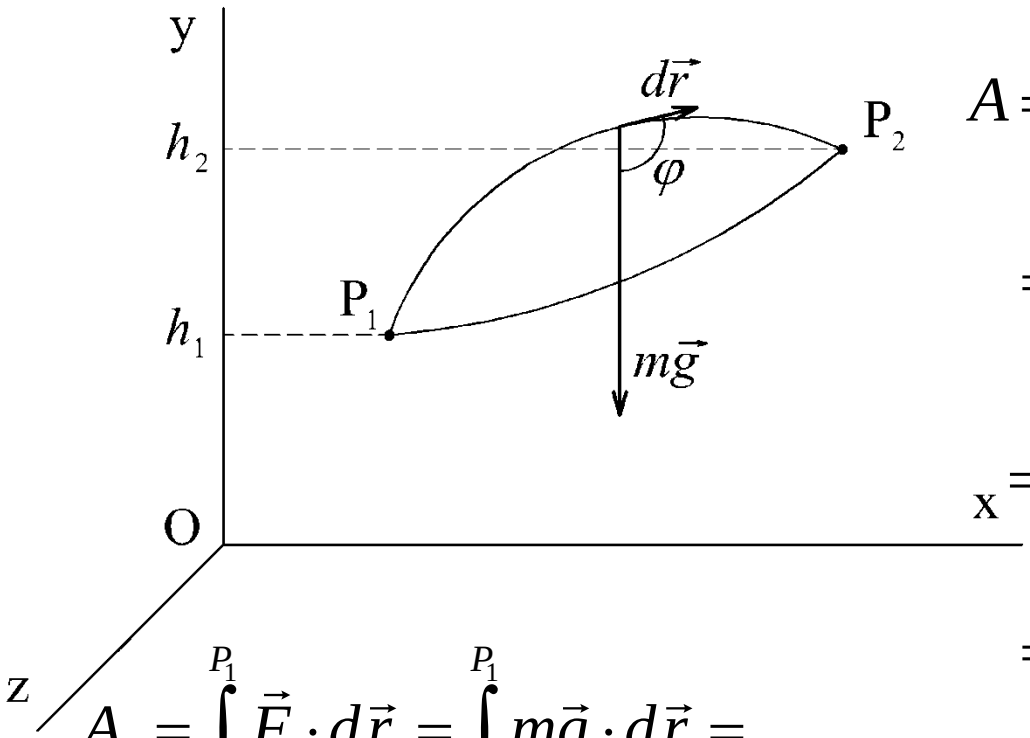
$$\Delta W_p = -\int_{R_z}^{R_z+h} \vec{F}\cdot d\vec{r} = \kappa m M_z \int_{R_Z}^{R_Z+h} \frac{1}{r^2}\,dr = \kappa m M_Z \left[-\frac{1}{r}\right]_{R_Z}^{R_Z+h} =$$

$$= \kappa m M_z \left(-\frac{1}{(R_z+h)} + \frac{1}{R_z}\right) = \kappa m M_z \left(\frac{h}{R_z(R_z+h)}\right) =$$

$$= \frac{\kappa M_z m h}{R_z^2}\left(\frac{R_z}{R_z+h}\right) = m g_0 h \left(\frac{R_z}{R_z+h}\right) \approx m g_0 h$$

$$\frac{\kappa M_z}{R_z^2} = g_0$$

# Tíhové pole




$$A = \int_{P_1}^{P_2} \vec{F} \cdot d\vec{r} = \int_{P_1}^{P_2} m\vec{g} \cdot d\vec{r}$$

$$A = \int_{x_1}^{x_2} F_x dx + \int_{y_1}^{y_2} F_y dy + \int_{z_1}^{z_2} F_z dz =$$

$$= \int_{x_1}^{x_2} 0 dx + \int_{y_1}^{y_2} (-mg) dy + \int_{z_1}^{z_2} 0 dz =$$

$$= \int_{y_1}^{y_2} (-mg) dy = (-mgy_2 + mgy_1) =$$

$$= (-mgh_2 + mgh_1) = mg(h_1 - h_2)$$

$$A_o = \int_{P_2}^{P_1} \vec{F} \cdot d\vec{r} = \int_{P_2}^{P_1} m\vec{g} \cdot d\vec{r} =$$

$$= \int_{y_2}^{y_1} (-mg) dy = (-mgy_1 + mgy_2) =$$

$$= (-mgh_1 + mgh_2) = mg(h_2 - h_1)$$

$$\oint_l \vec{F} \cdot d\vec{r} = 0$$

$$\Delta W_p = mg(h_2 - h_1)$$

# Konzervativní a nekonzervativní síly

**konzervativní:**

Práce po uzavřené křivce je rovna nule. $\oint_l \vec{F} \cdot d\vec{r} = 0$

síla pružiny

tíhová síla

gravitační síla

centrální síly

**nekonzervativní:**

síla tření

# Princip pohybu satelitů

$$F_g = F_d$$

$$\kappa \frac{mM_Z}{(R+h)^2} = m\frac{v^2}{(R+h)}$$

$$v = \sqrt{\frac{\kappa M_Z}{R+h}} = \sqrt{\frac{gR^2}{R+h}}$$

$$\kappa \frac{mM_Z}{R^2} = mg$$