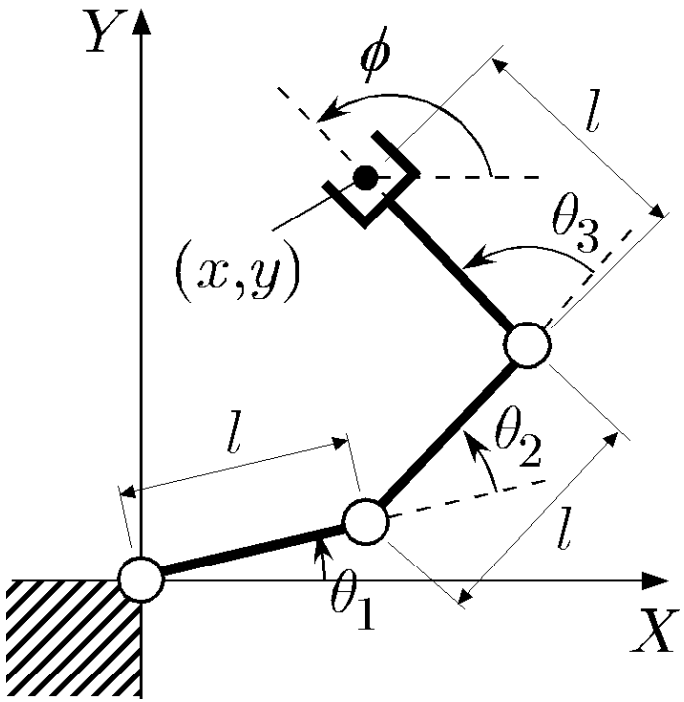
# 機構学
# Part9：センサの機構

金子真

# 課題1：3リンクロボットについて以下の問いに答えよ

手先位置・姿勢(x, y, $\phi$)に対して特異姿勢を求め図示せよ.



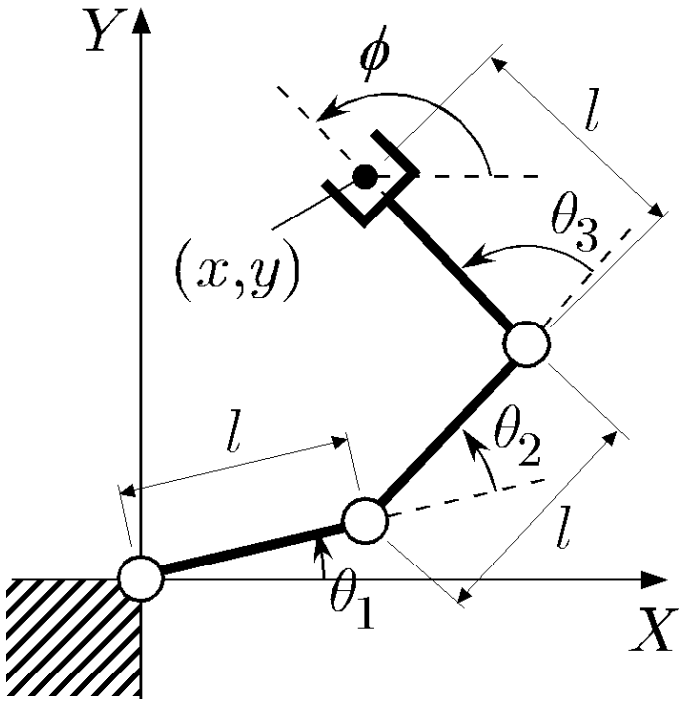
# 課題1： 解答

$$d\boldsymbol{x} = \boldsymbol{J}\, d\boldsymbol{\theta}$$

$$dx = -lS_1 d\theta_1 - lS_{12}(d\theta_1 + d\theta_2) - lS_{123}(d\theta_1 + d\theta_2 + d\theta_3)$$
$$dy = lC_1 d\theta_1 + lC_{12}(d\theta_1 + d\theta_2) + lC_{123}(d\theta_1 + d\theta_2 + d\theta_3)$$
$$d\phi = d\theta_1 + d\theta_2 + d\theta_3$$

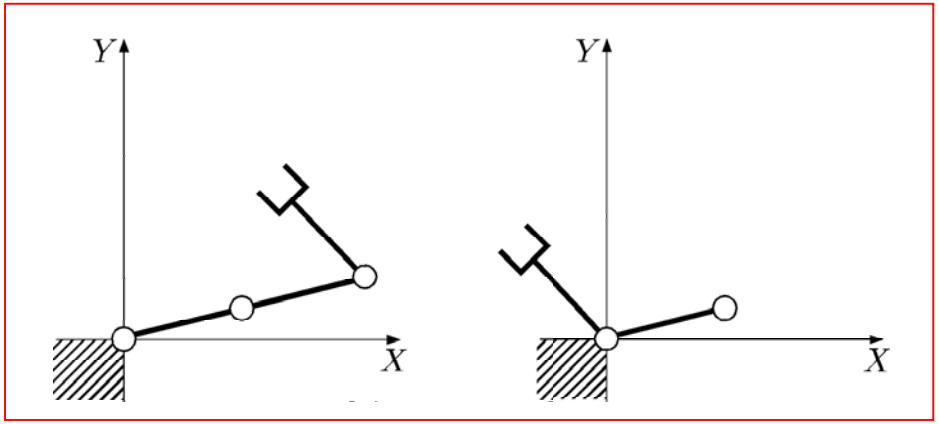
$$\therefore \boldsymbol{J} = \begin{bmatrix} -lS_1 - lS_{12} - lS_{123} & -lS_{12} - lS_{123} & -lS_{123} \\ lC_1 + lC_{12} + lC_{123} & lC_{12} + lC_{123} & lC_{123} \\ 1 & 1 & 1 \end{bmatrix}$$

$$S_1 = \sin\theta_1, \quad S_{12} = \sin(\theta_1 + \theta_2), \quad S_{123} = \sin(\theta_1 + \theta_2 + \theta_3)$$
$$C_1 = \cos\theta_1, \quad C_{12} = \cos(\theta_1 + \theta_2), \quad C_{123} = \cos(\theta_1 + \theta_2 + \theta_3)$$

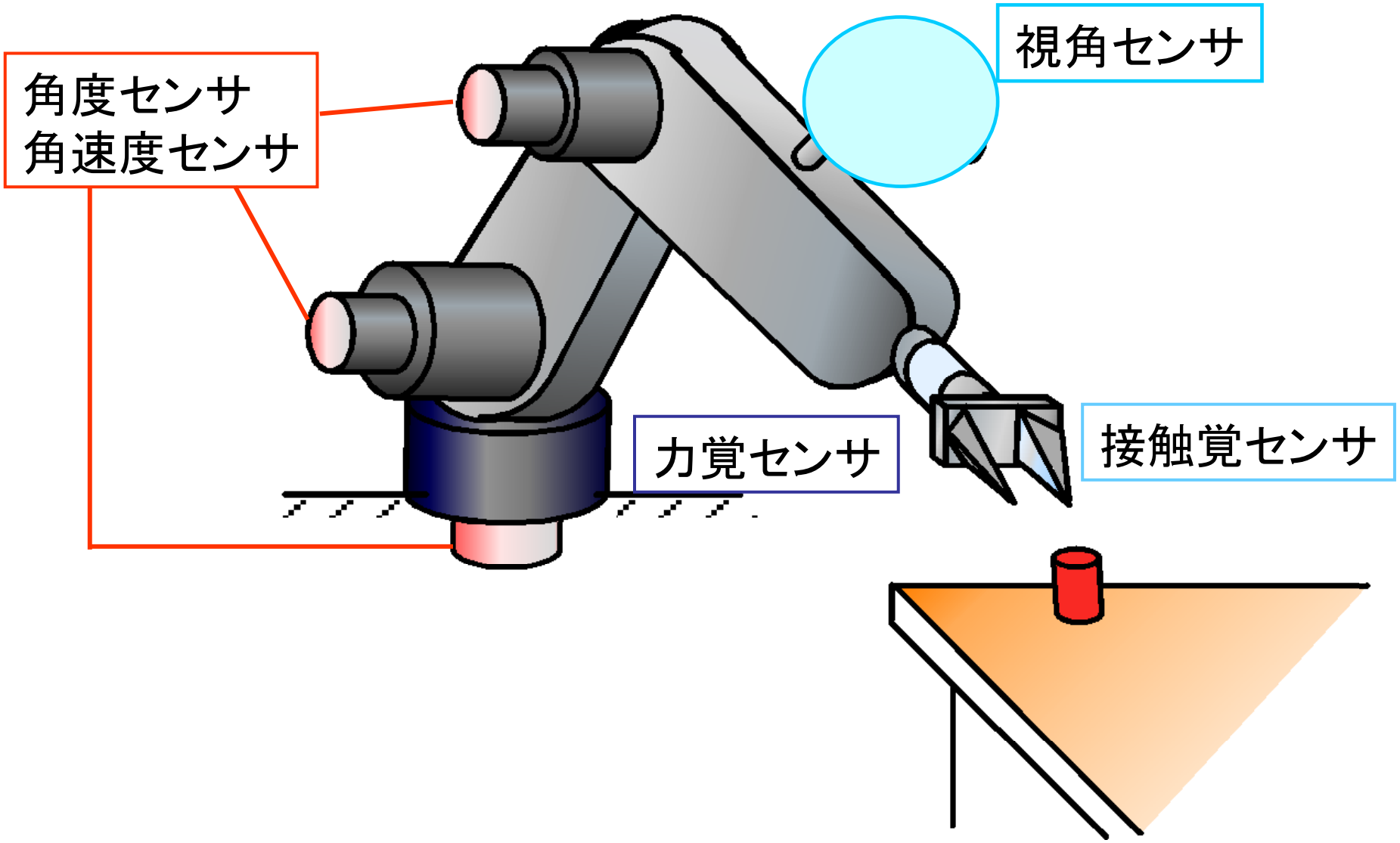



$$|\boldsymbol{J}| = 0$$

$$l^2 \sin\theta_2 = 0 \qquad \therefore \theta_2 = n\pi$$



# ロボットセンサ



# ロボットセンサの分類

- 内界センサ
  - 角度センサ
  - 角速度センサ
  - 姿勢センサ
- 外界センサ
  - 触覚センサ
    - 力覚センサ
    - 接触覚センサ
    - 圧覚センサ
    - すべり覚センサ
  - 非接触センサ
    - ビジョンセンサ（視覚）
    - 近接覚センサ

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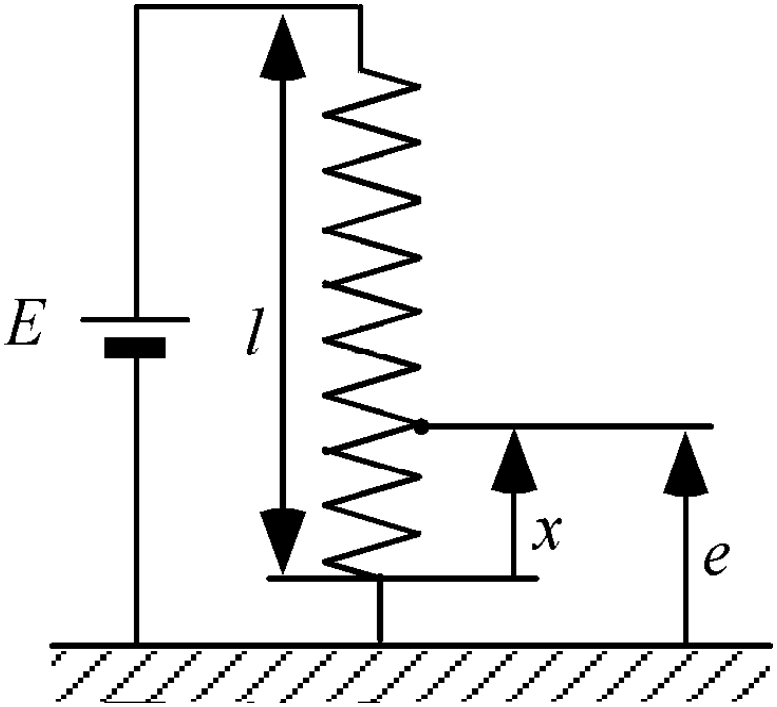
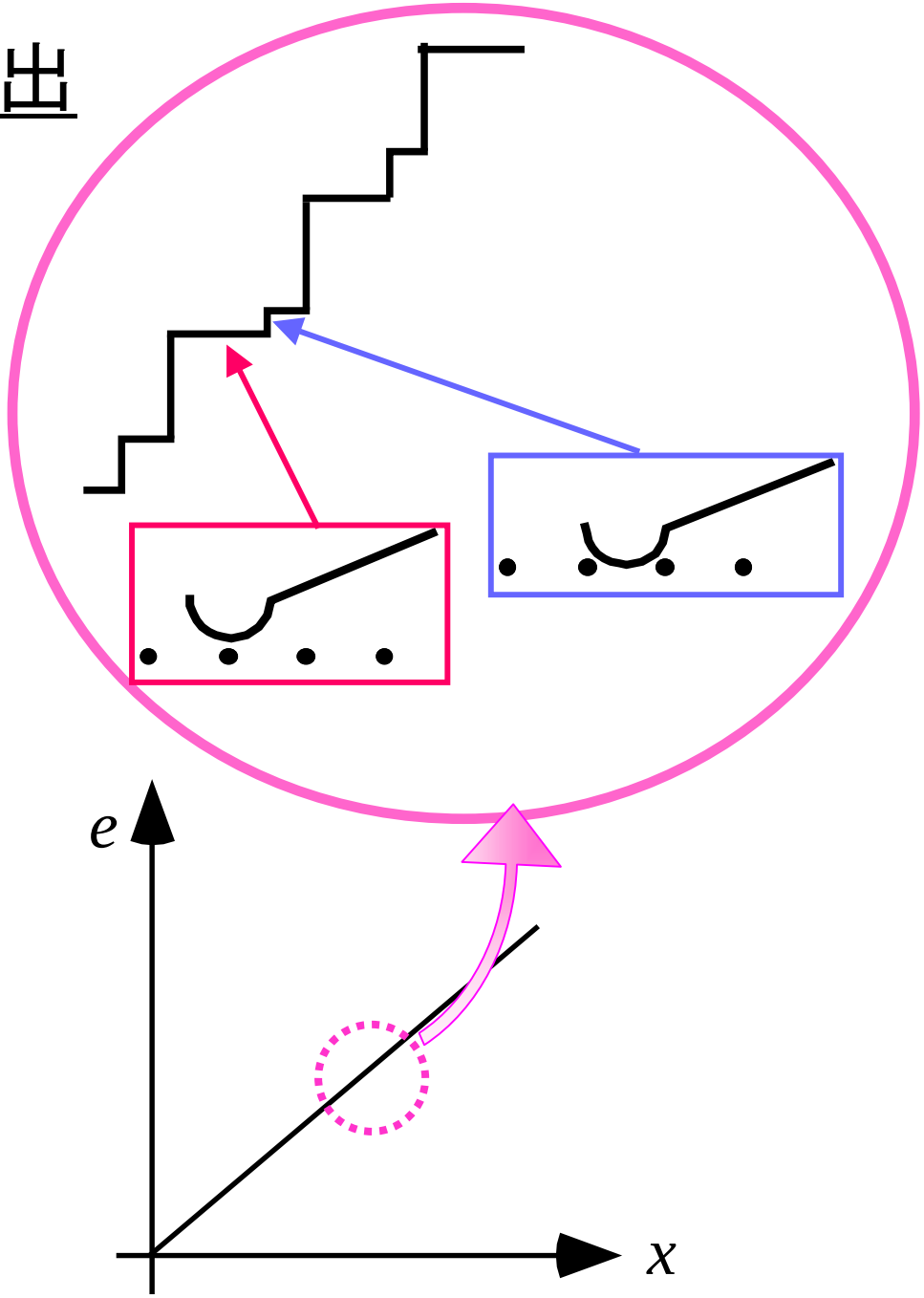
    - すべり覚センサ
  - 非接触センサ
    - ビジョンセンサ（視覚）
    - 近接覚センサ

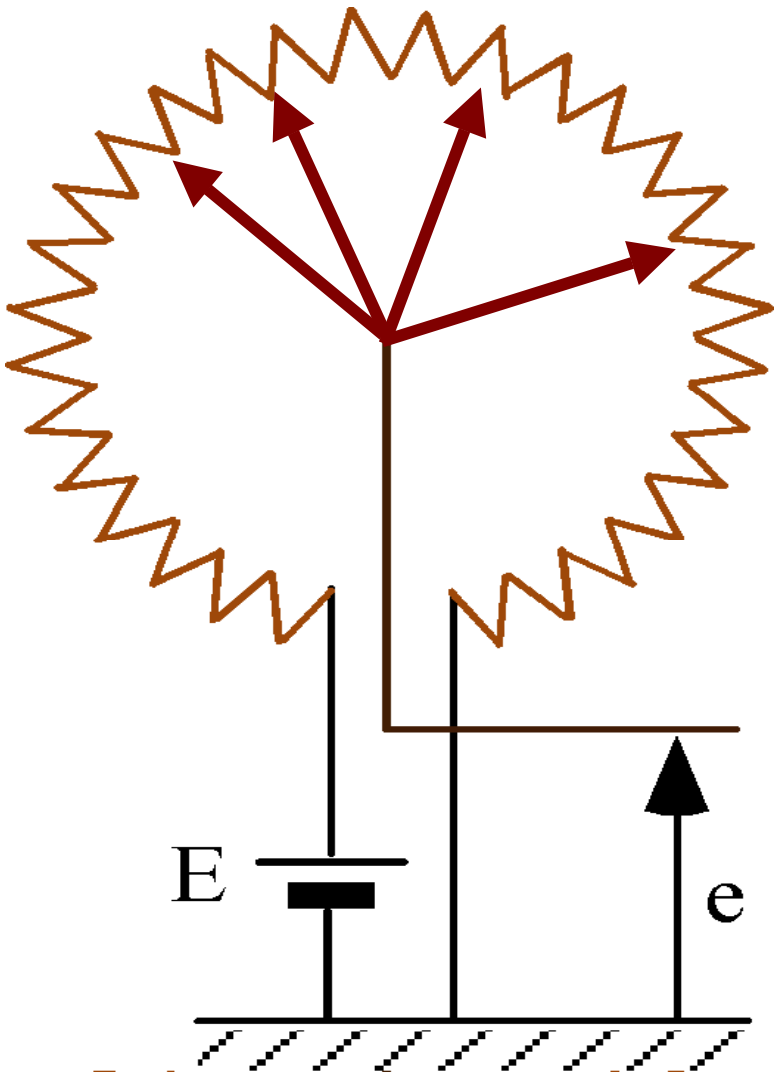
# 抵抗を使用した位置検出



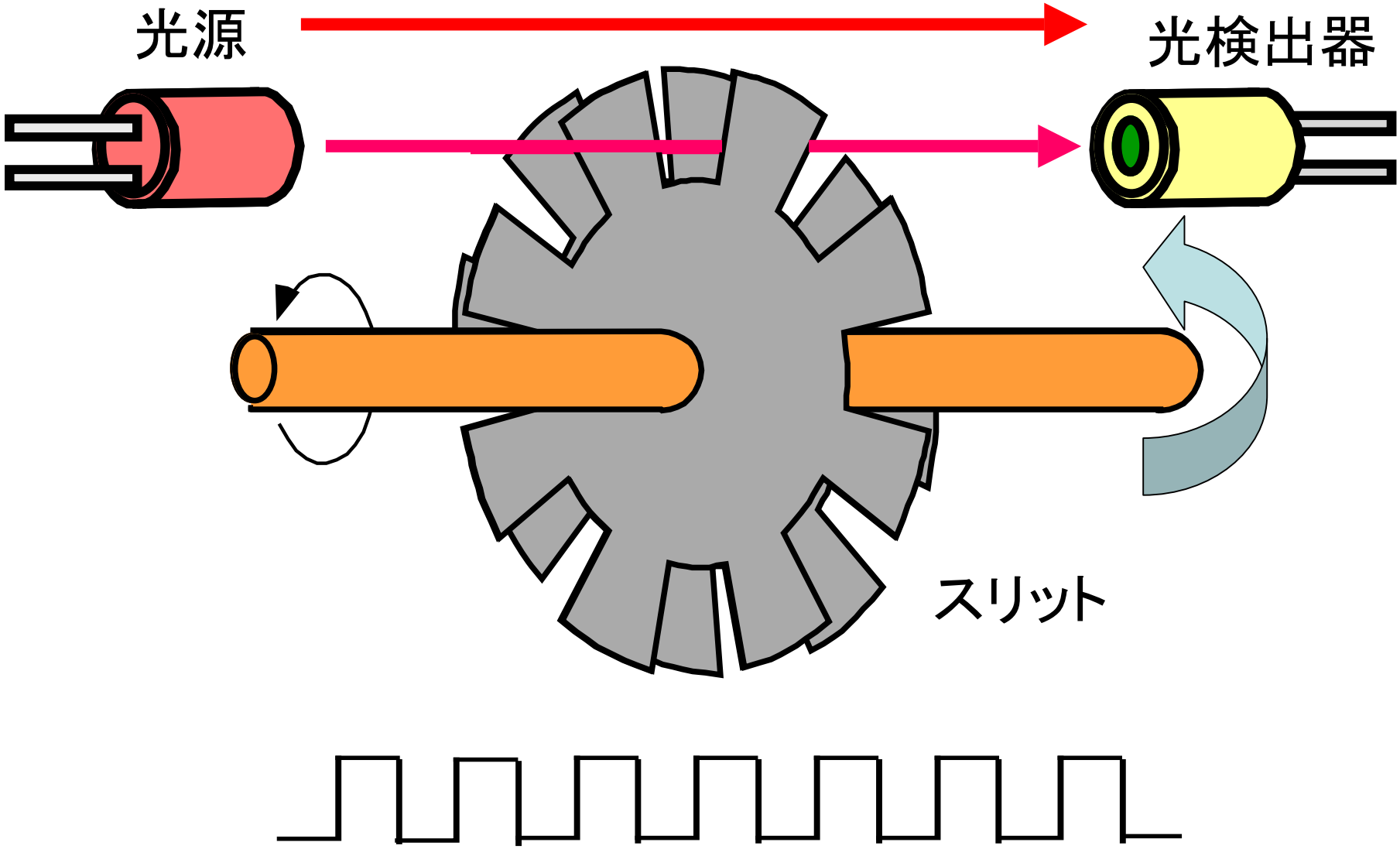

$$e = \frac{x}{l} E$$

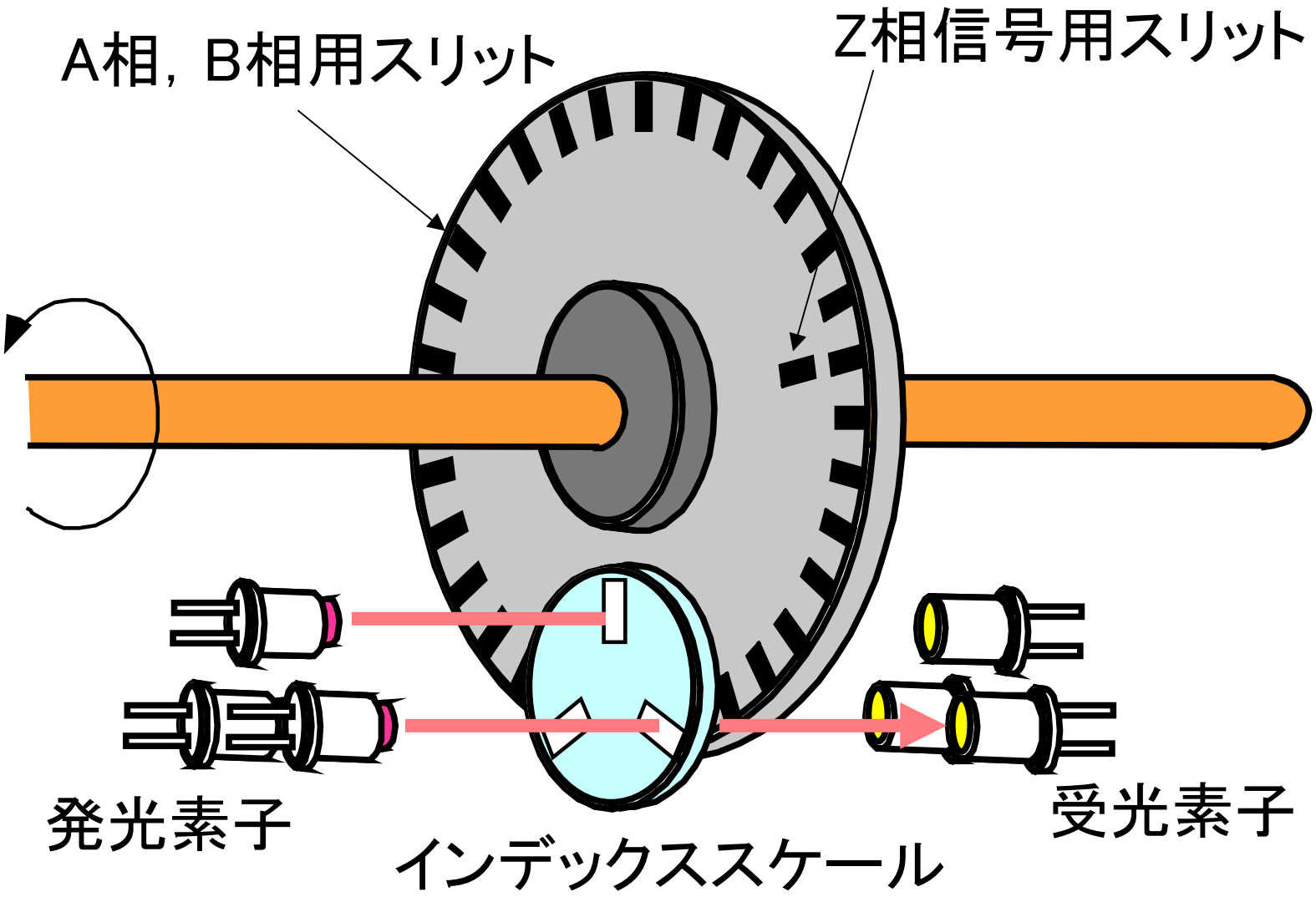
# 角度センサ（ポテンショメータ）

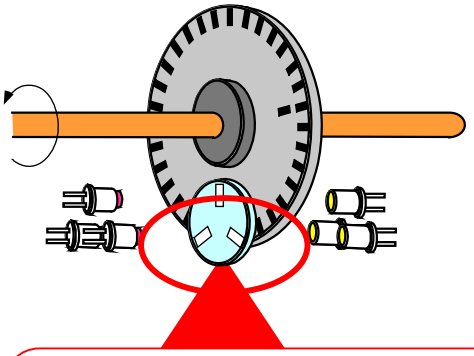


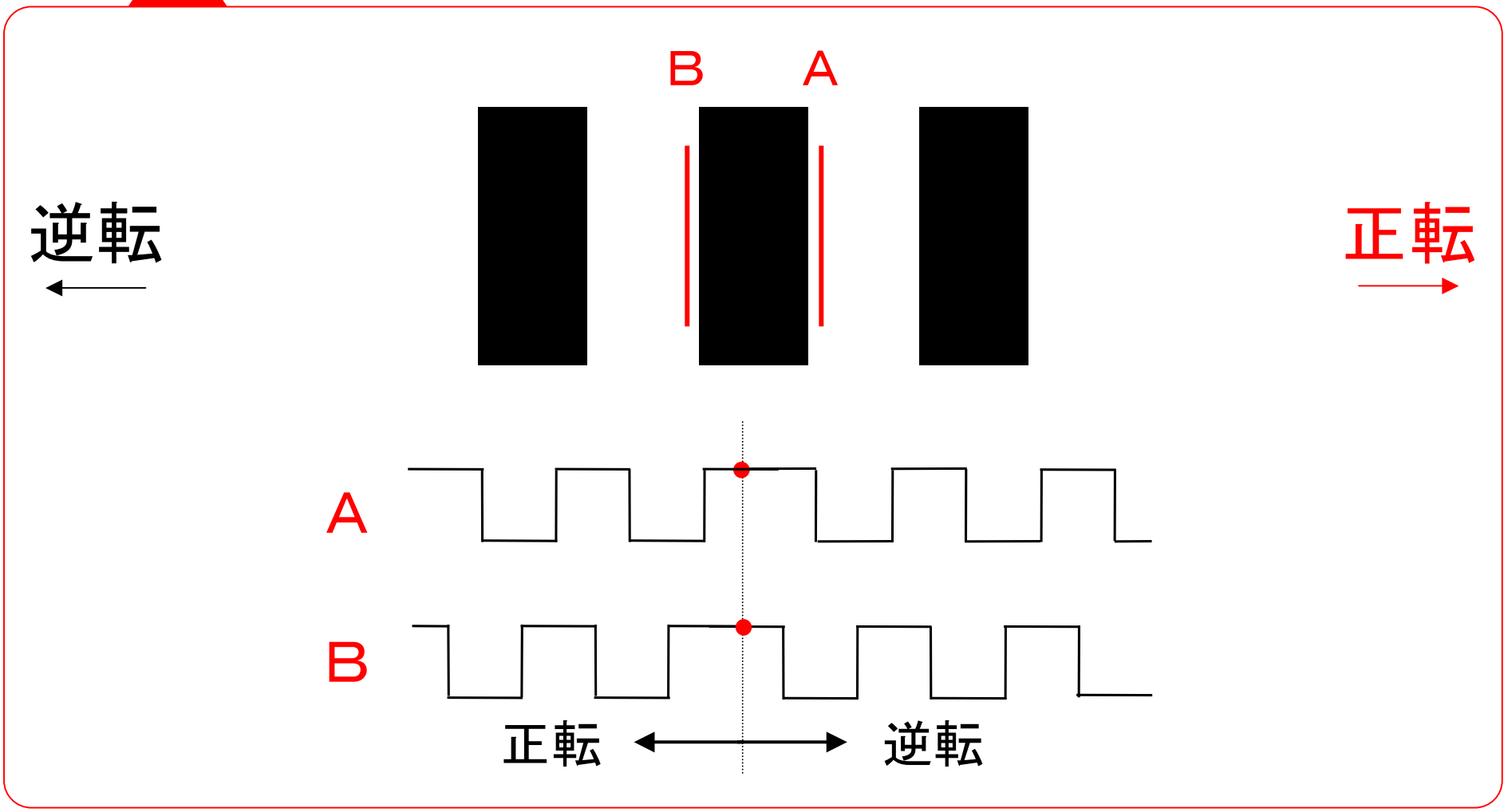

円形抵抗

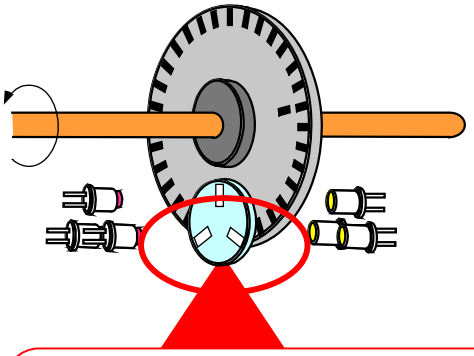
# 角度センサ（エンコーダ）

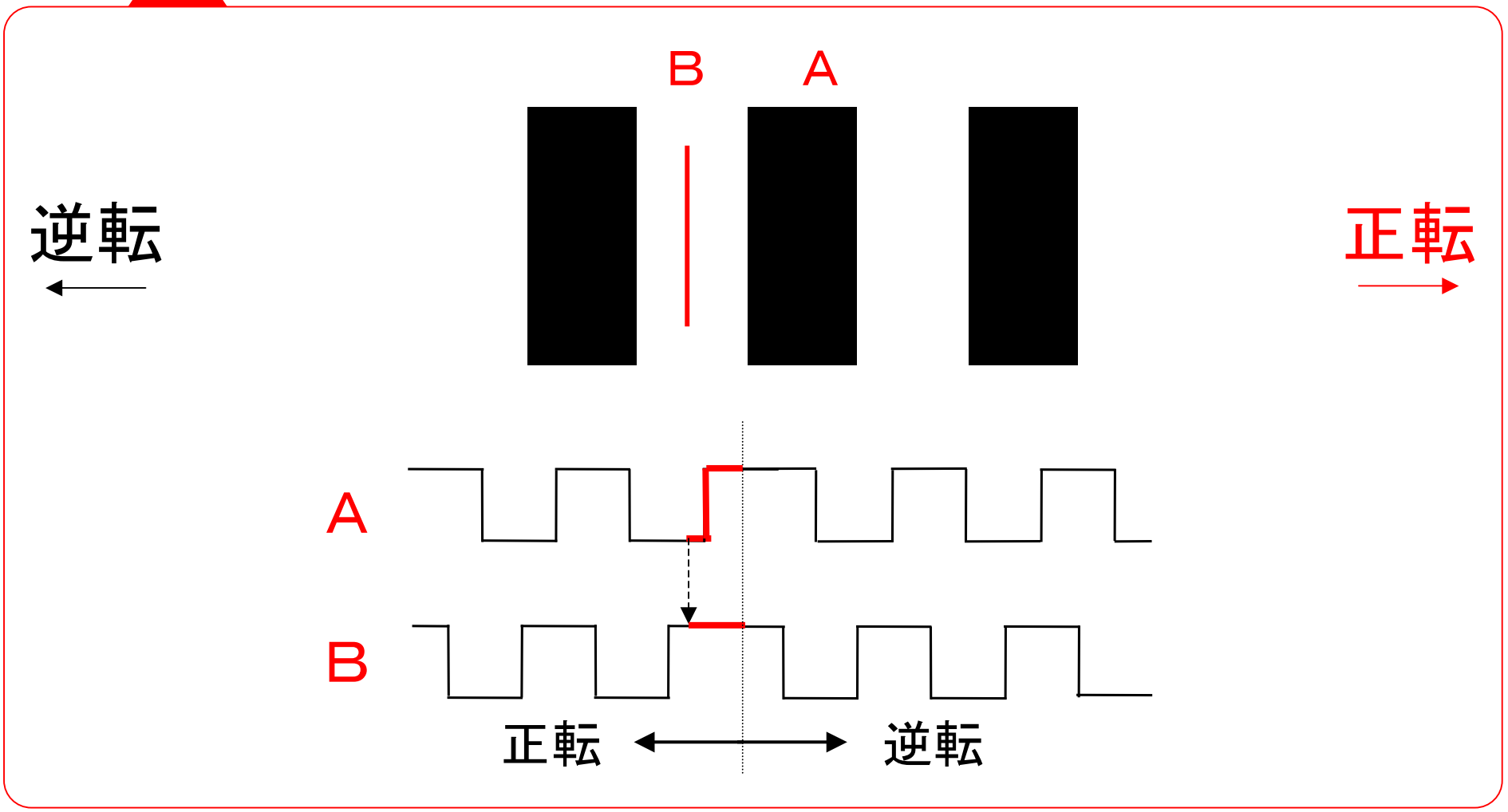


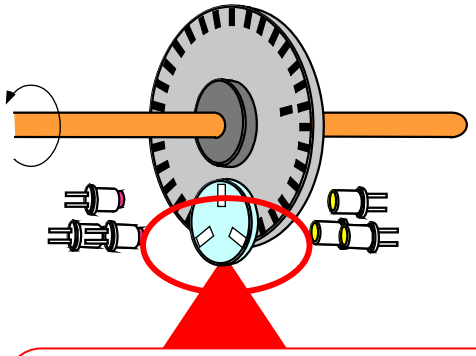

A相，B相用スリット
Z相信号用スリット
発光素子
インデックススケール
受光素子

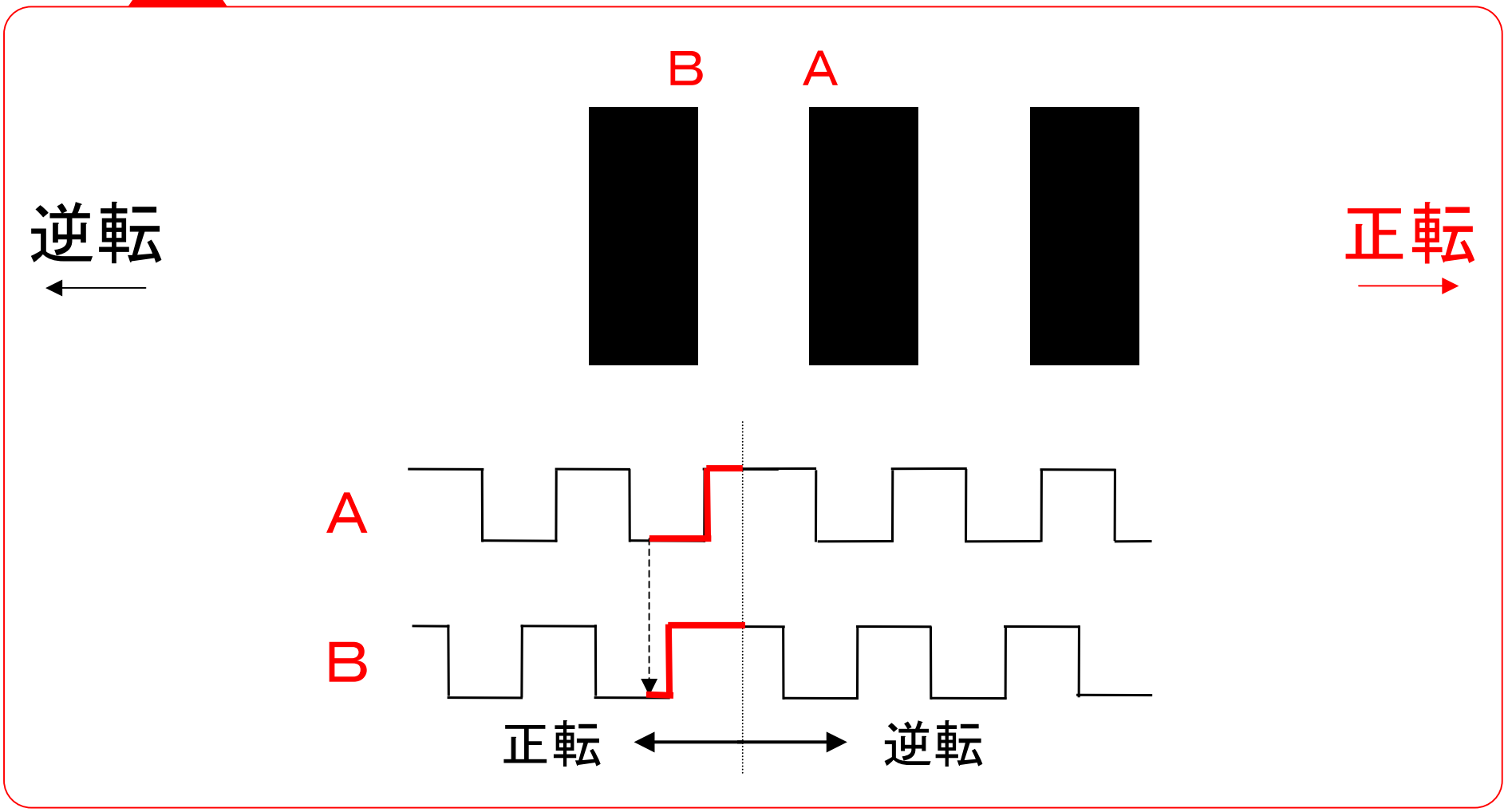


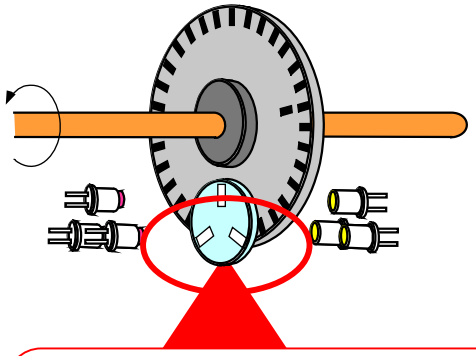

B
A
逆転
正転
A
B
正転
逆転

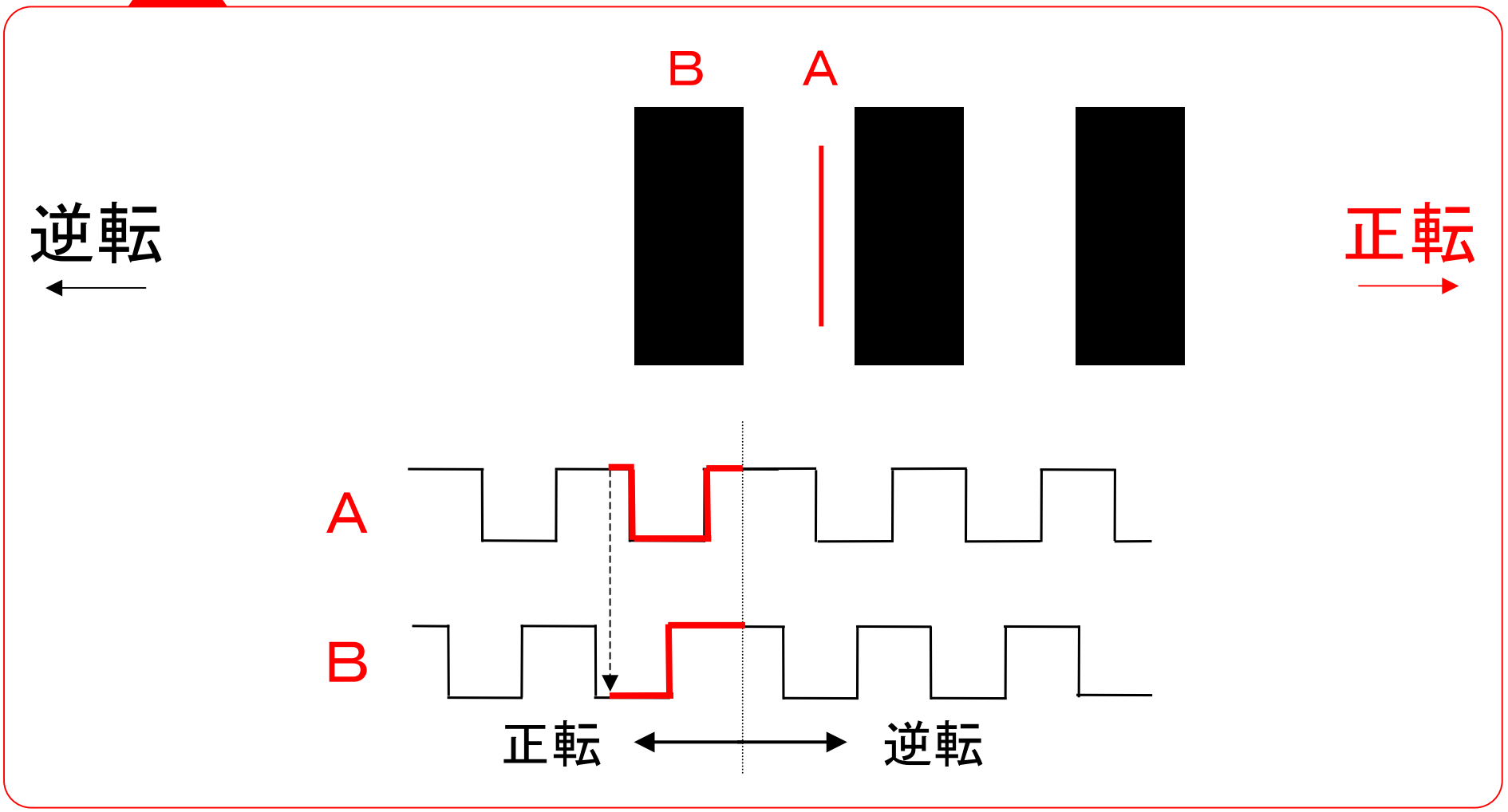


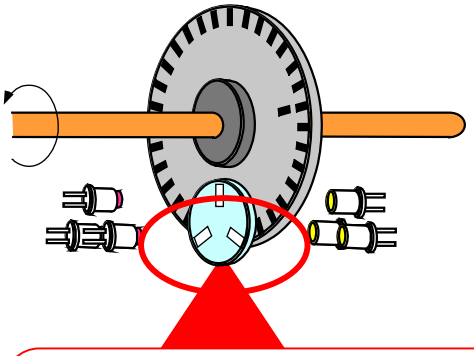

B
A
逆転
正転
A
B
正転
逆転

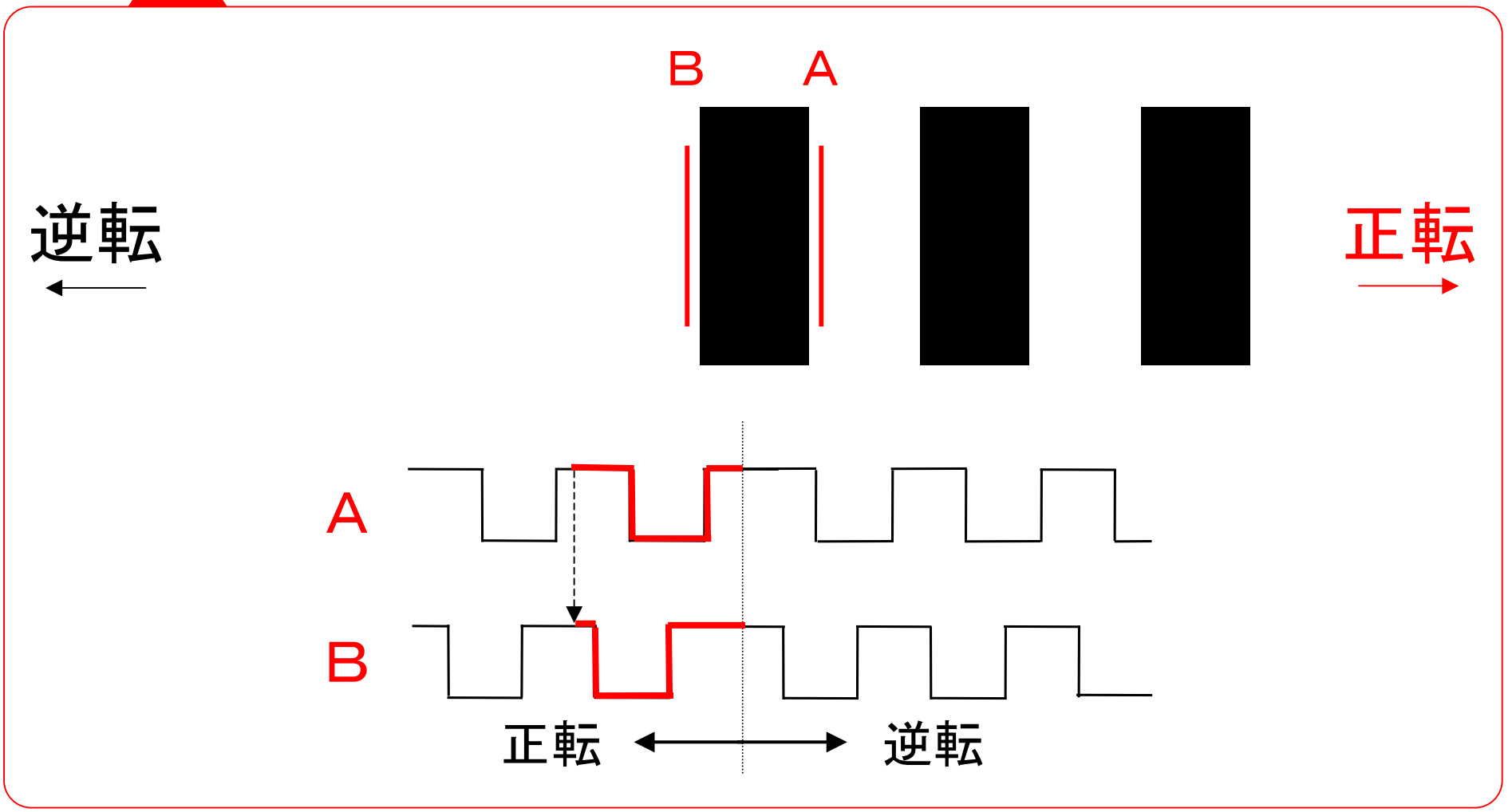


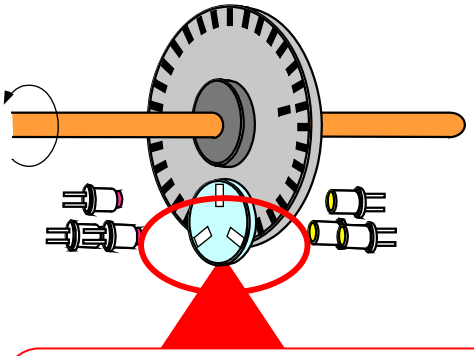

B
A
逆転
正転
A
B
正転
逆転

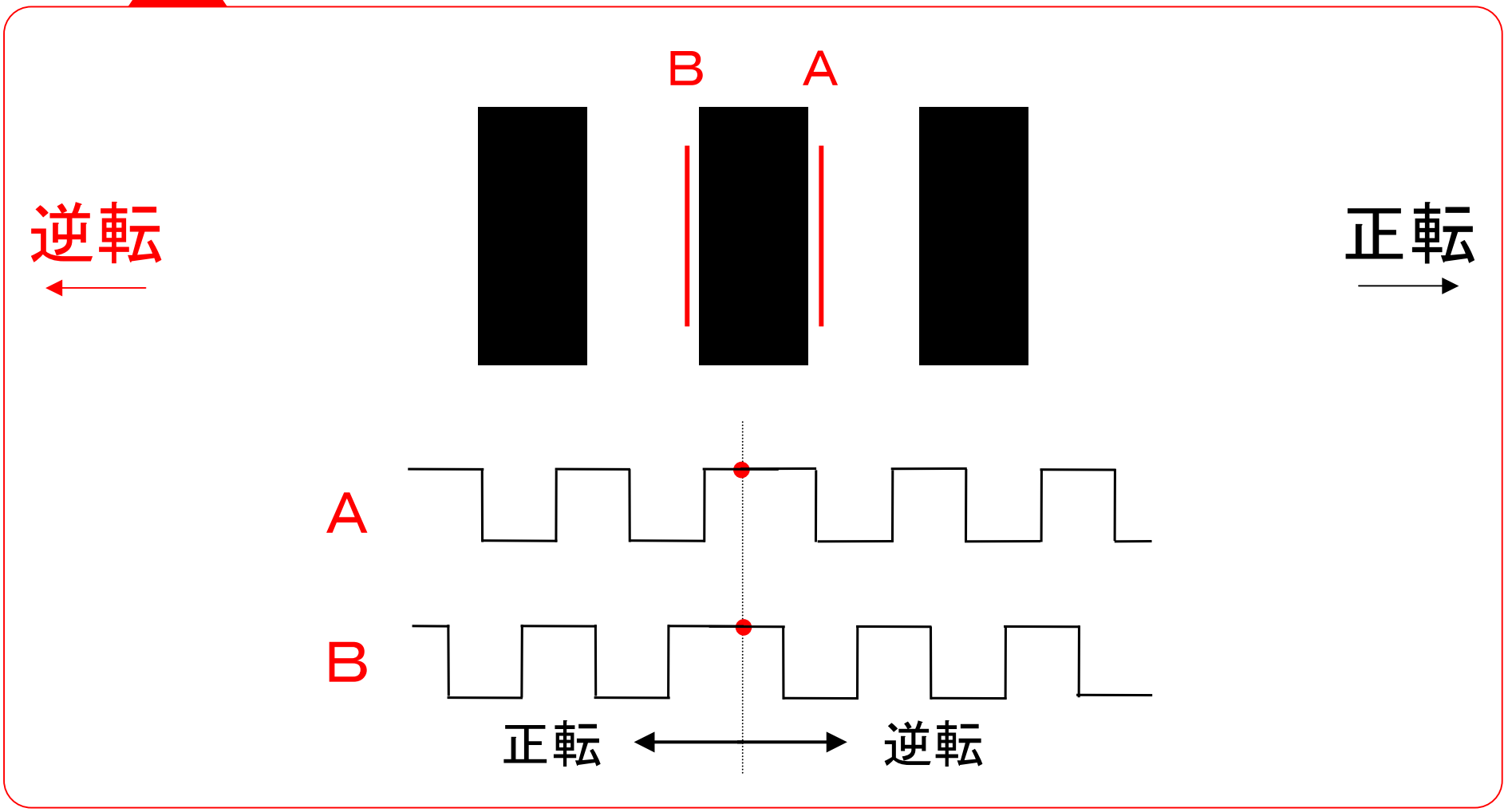


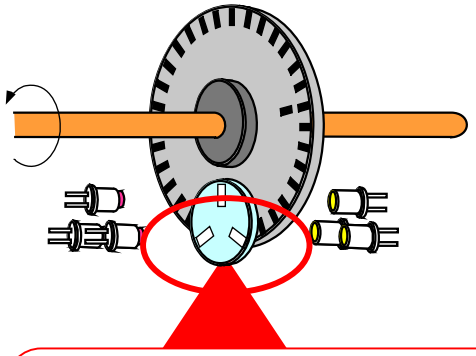

B
A
逆転
正転
A
B
正転
逆転

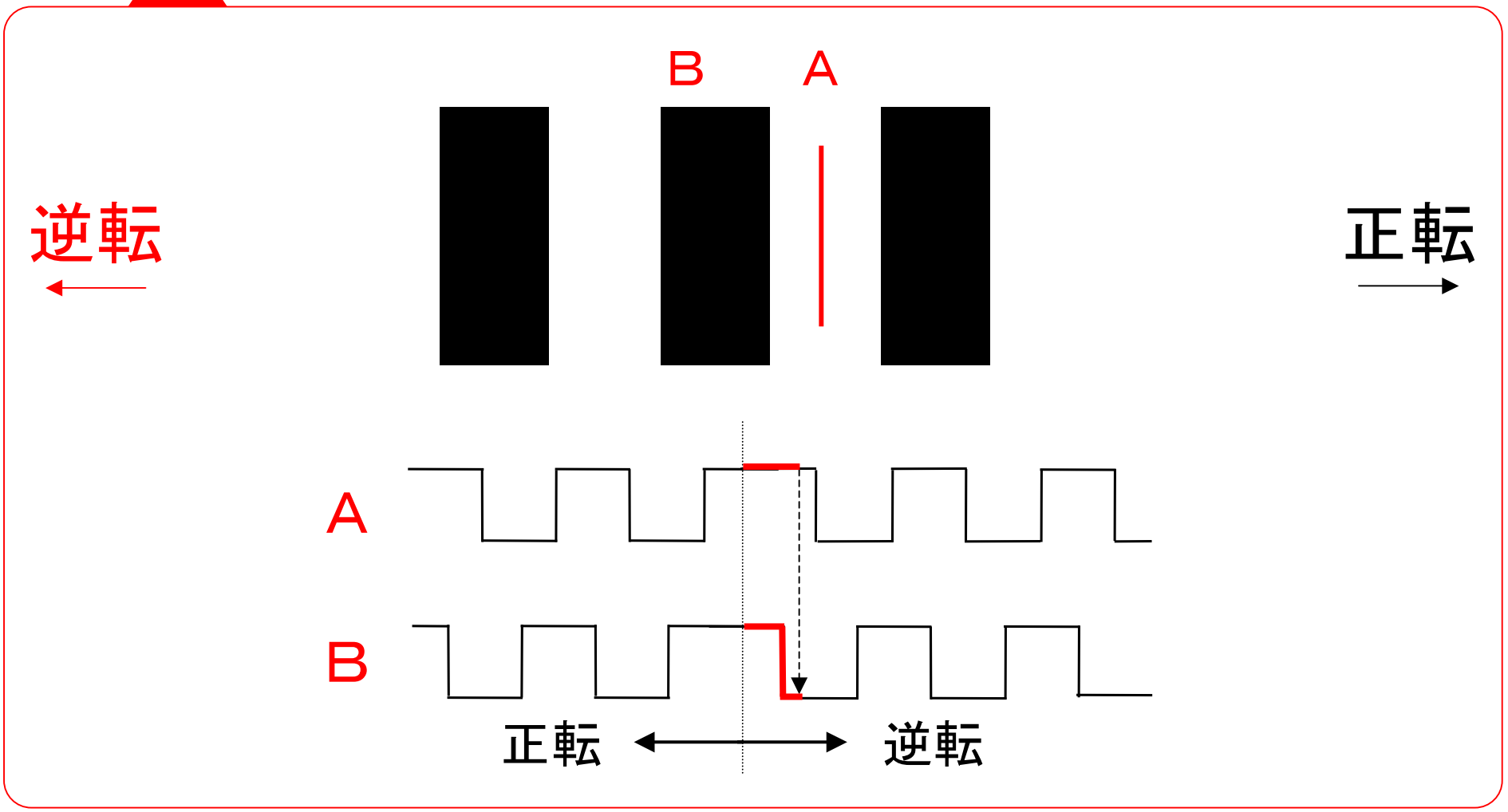


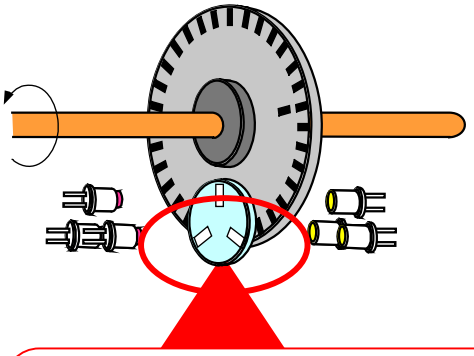

B
A
逆転
正転
A
B
正転
逆転

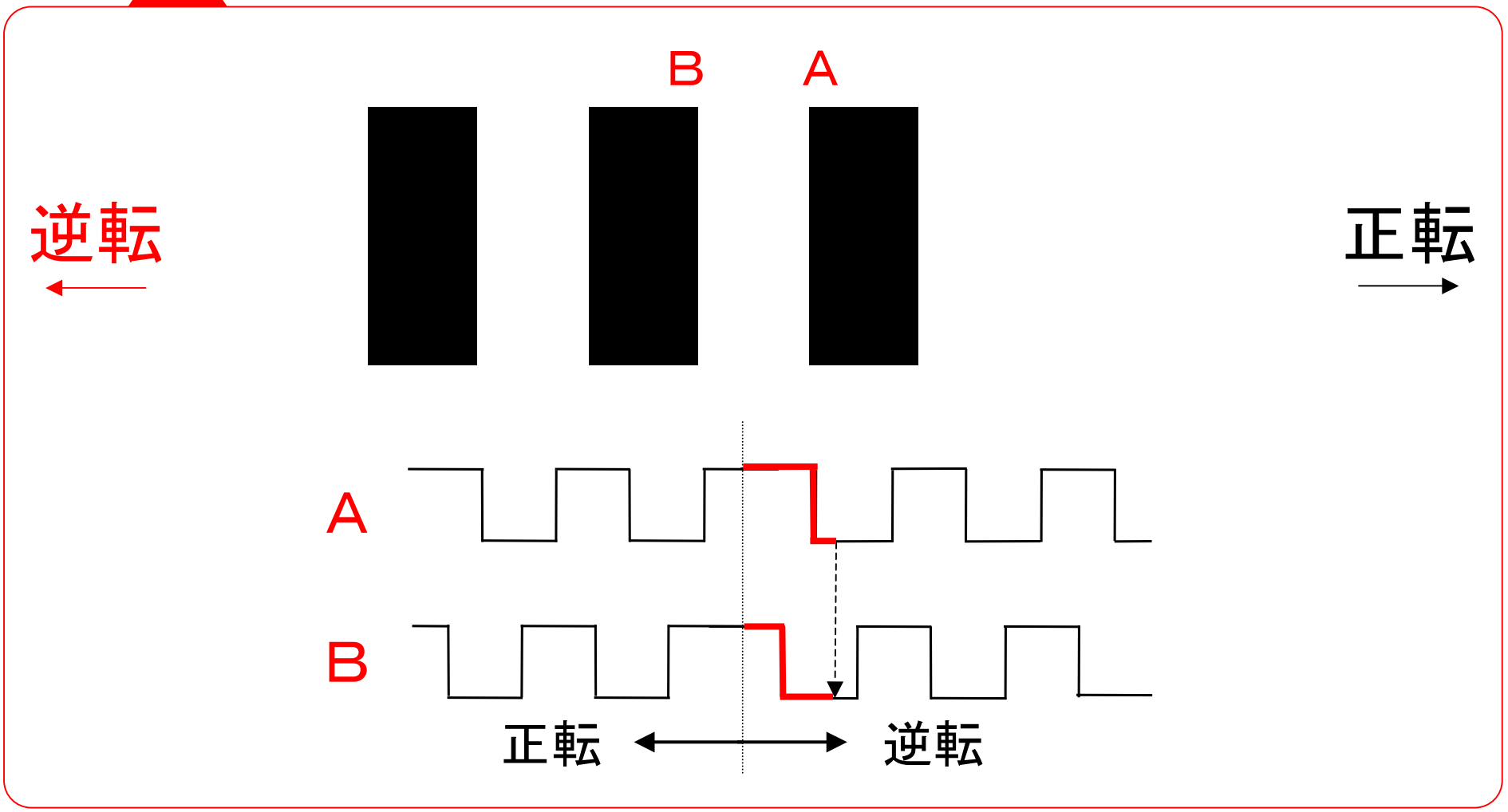


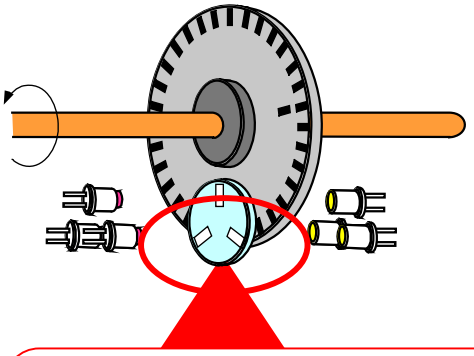

B
A
逆転
正転
A
B
正転
逆転

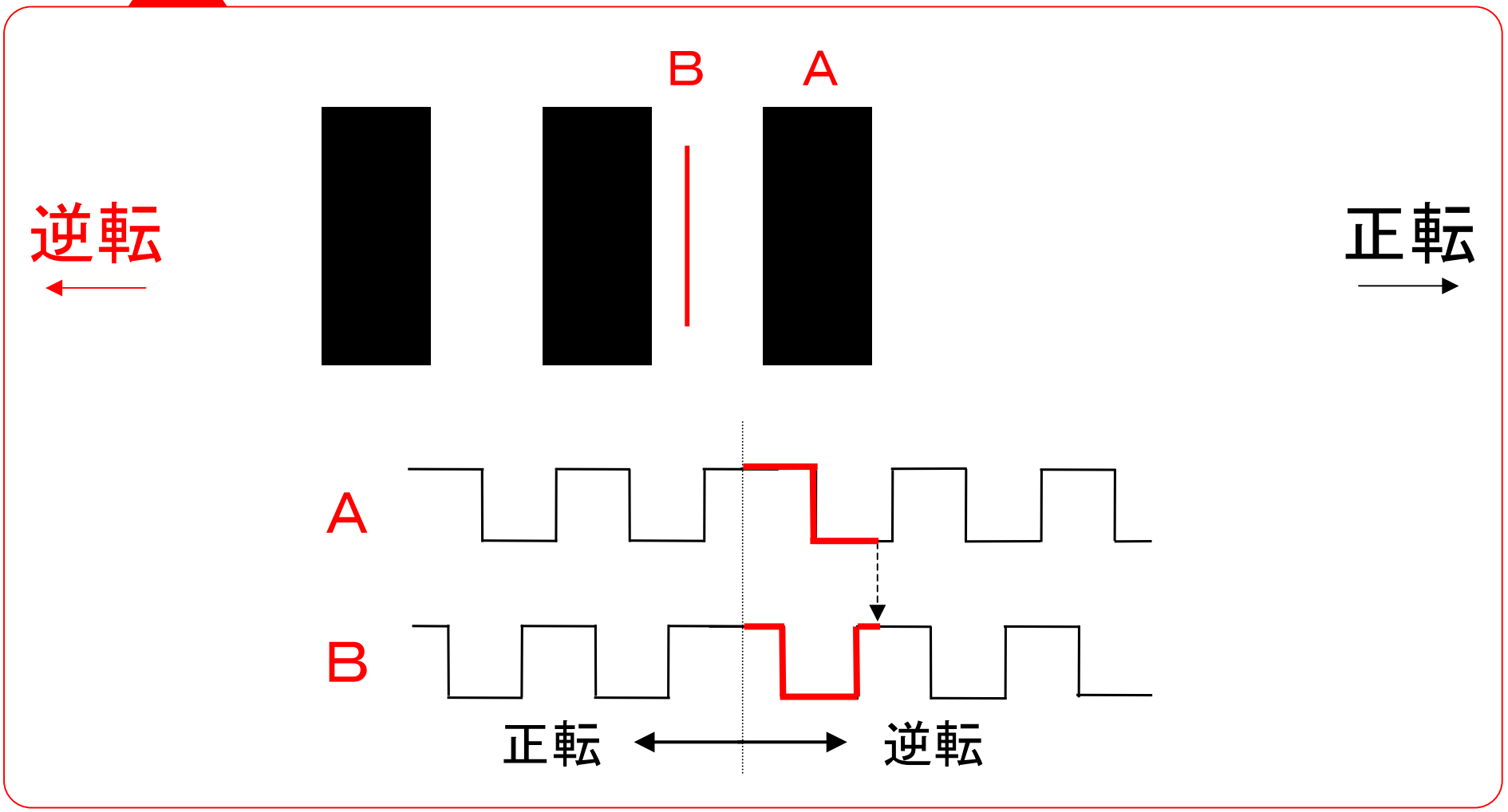


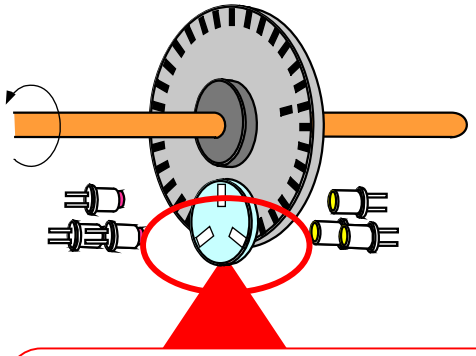

B
A
逆転
正転
A
B
正転
逆転

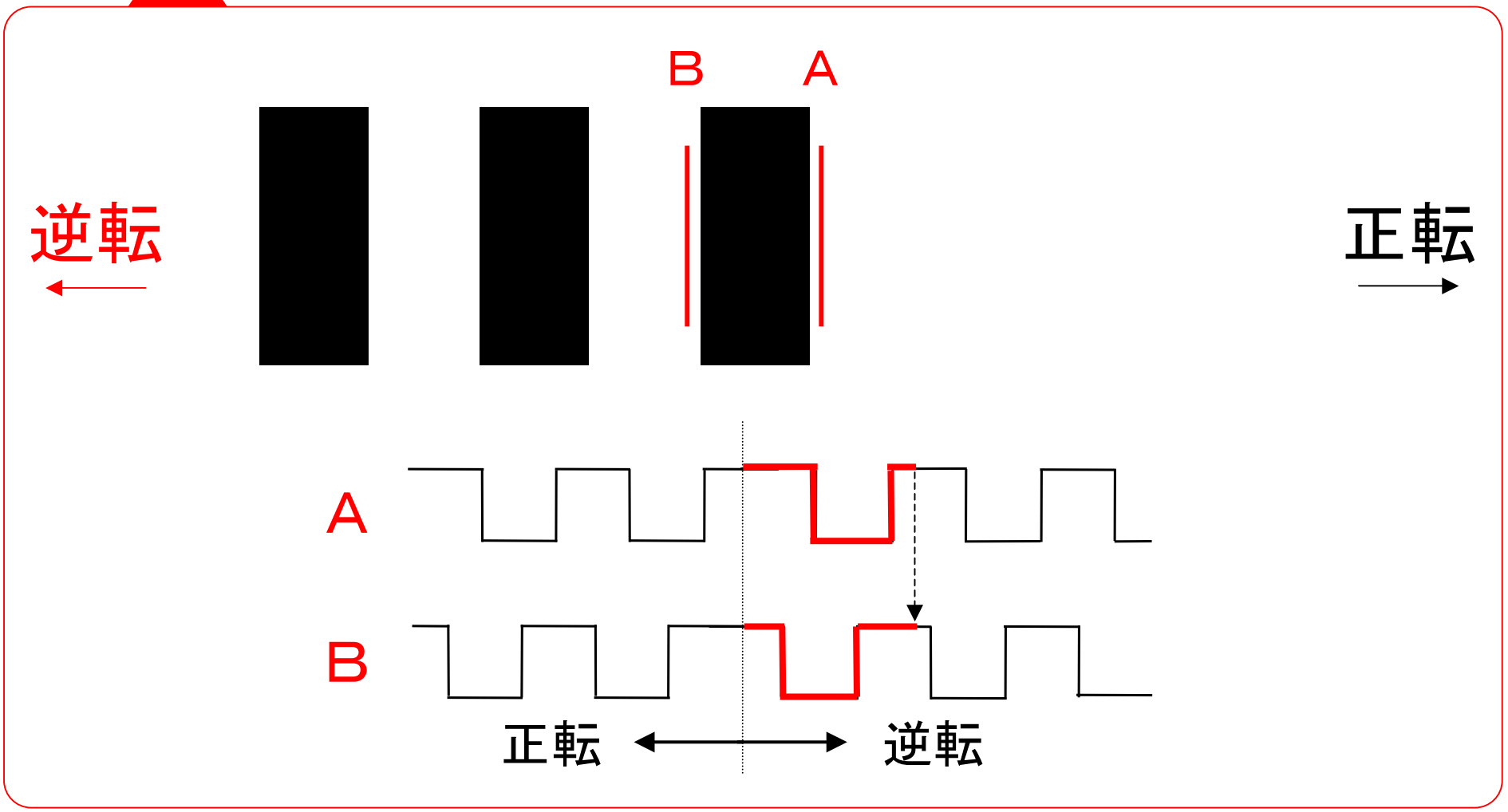



B
A
逆転
正転
A
B
正転
逆転

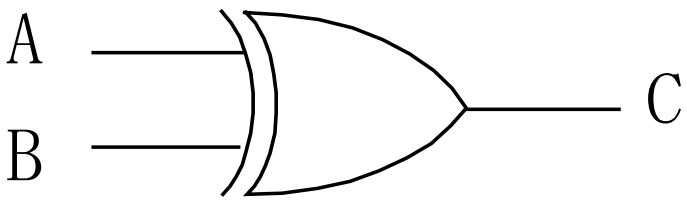



B
A
逆転
正転
A
B
正転
逆転

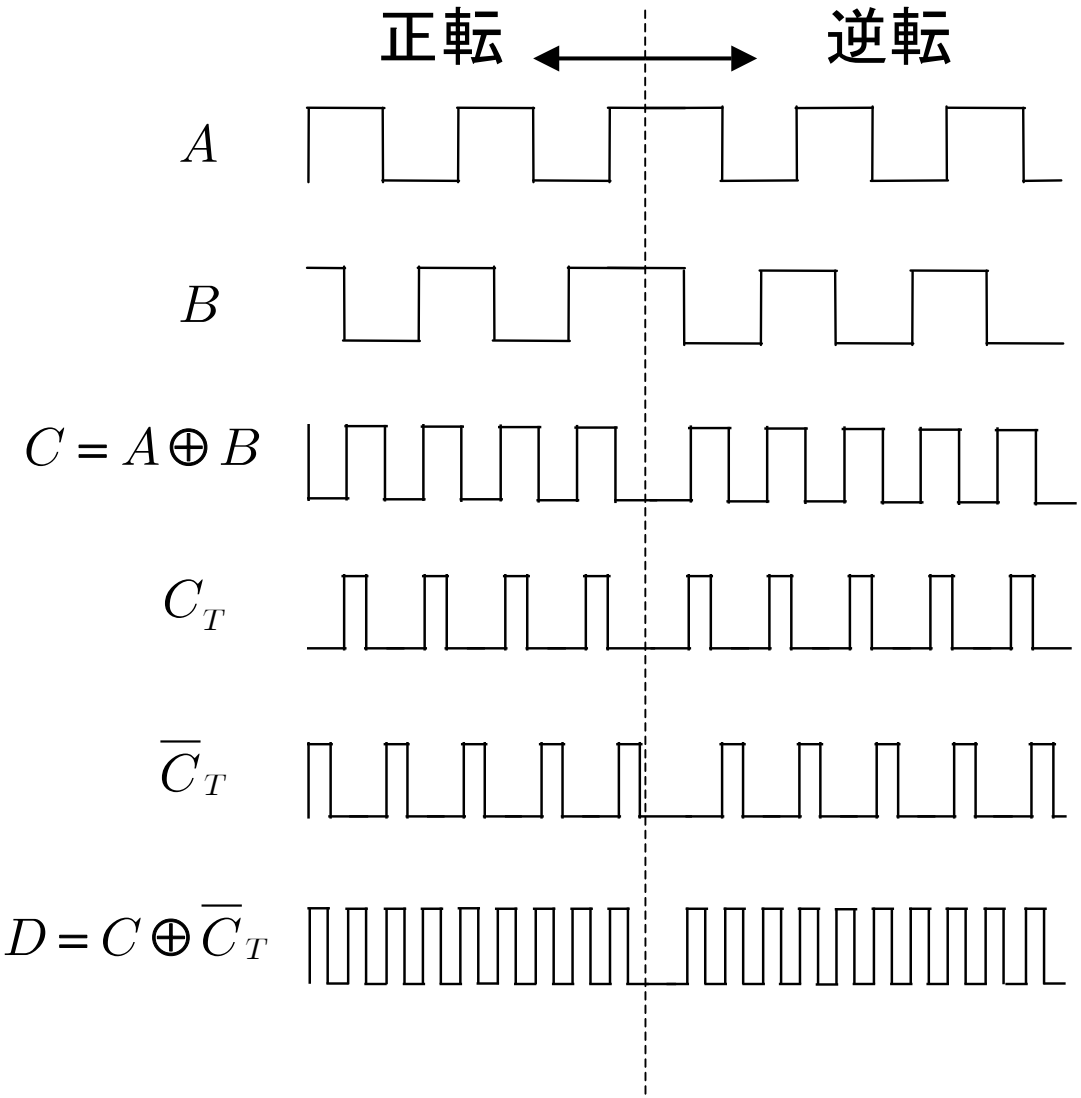



B
A
逆転
正転
A
B
正転
逆転

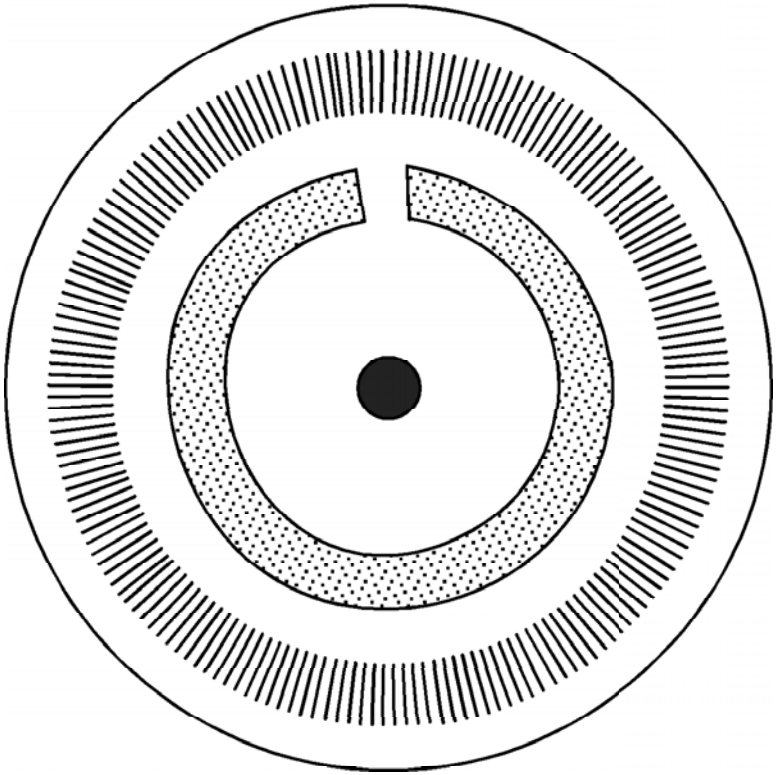
# エンコーダA相，B相信号処理



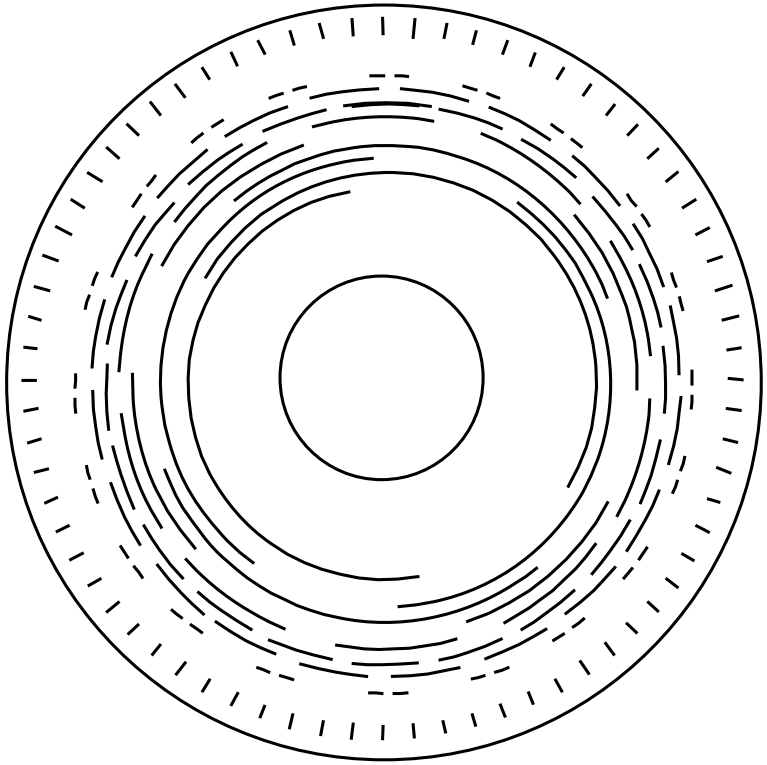

| A | B | C |
|---|---|---|
| L | L | L |
| L | H | H |
| H | L | H |
| H | H | L |



インクリメンタル



アブソリュート



# ロボットセンサの分類

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  - 角速度センサ
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- 外界センサ
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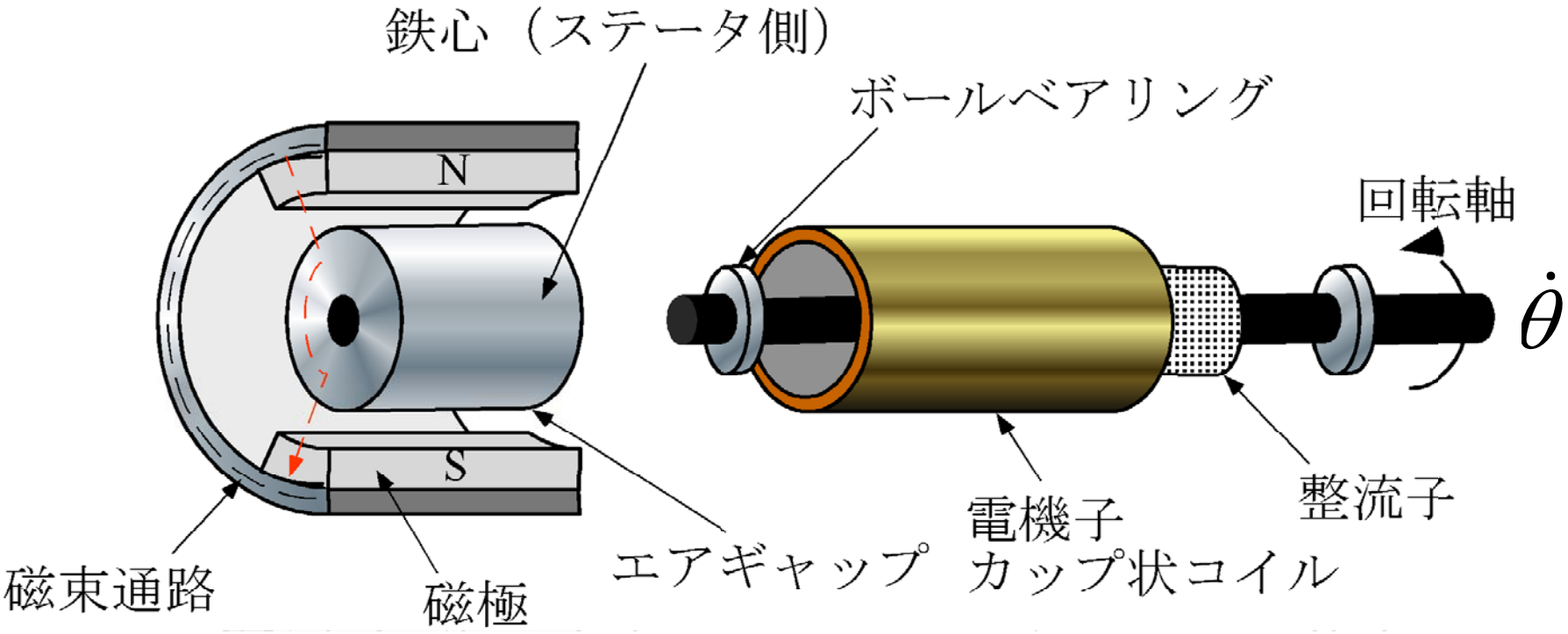
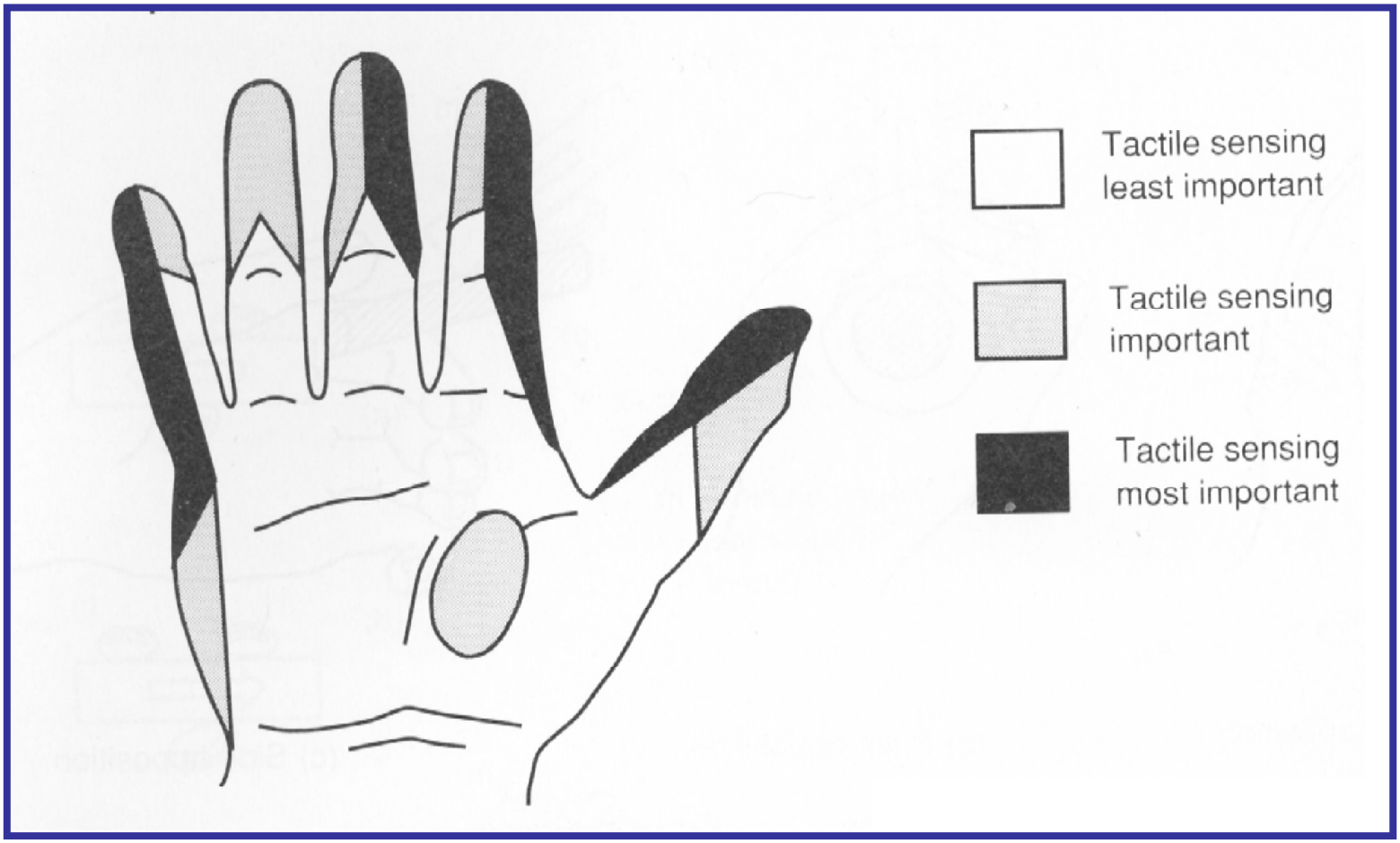
# 角速度センサ




$$e = k\dot{\theta}$$

自転車の発電機と同じ原理


Tactile sensing least important
Tactile sensing important
Tactile sensing most important

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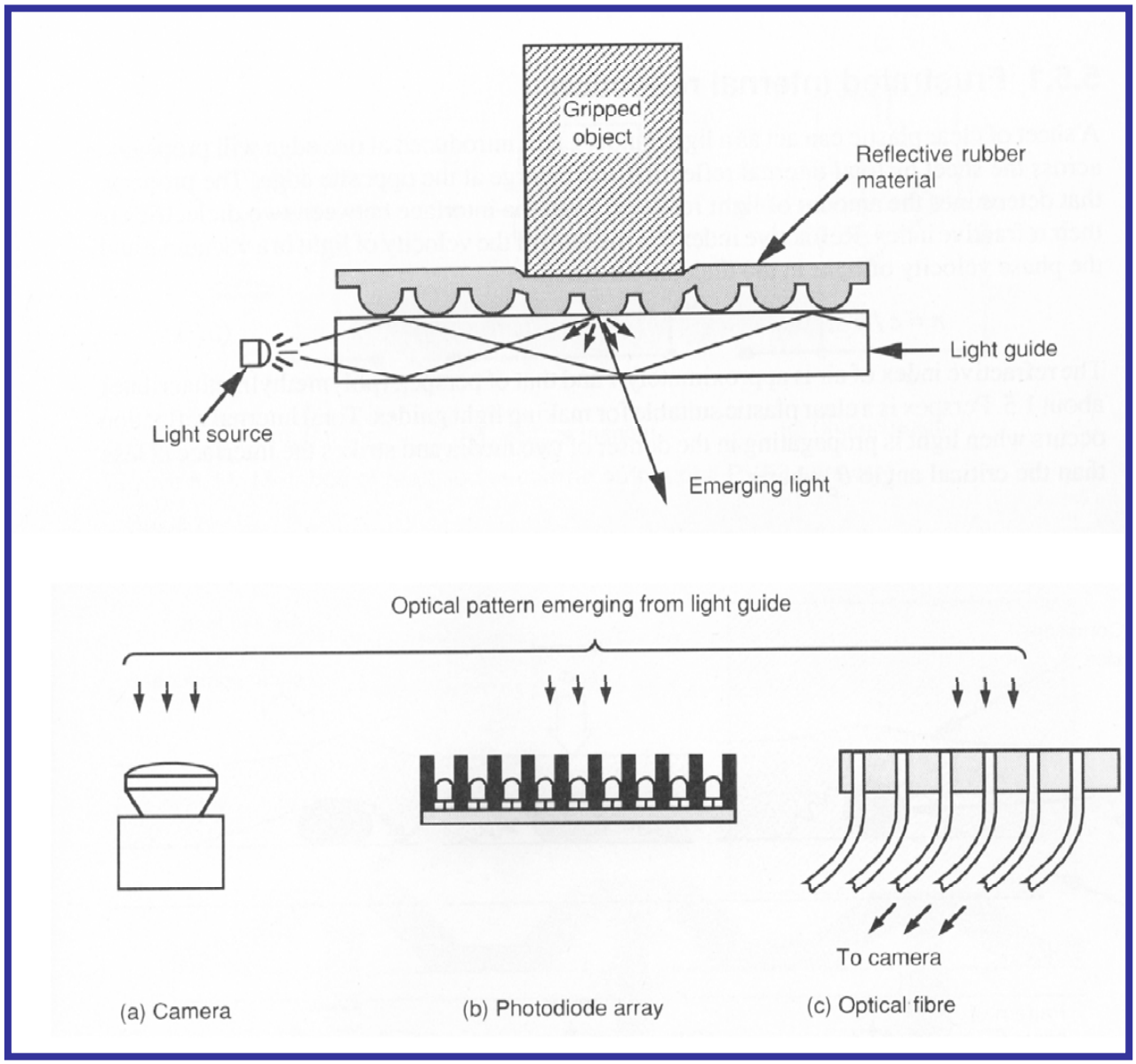
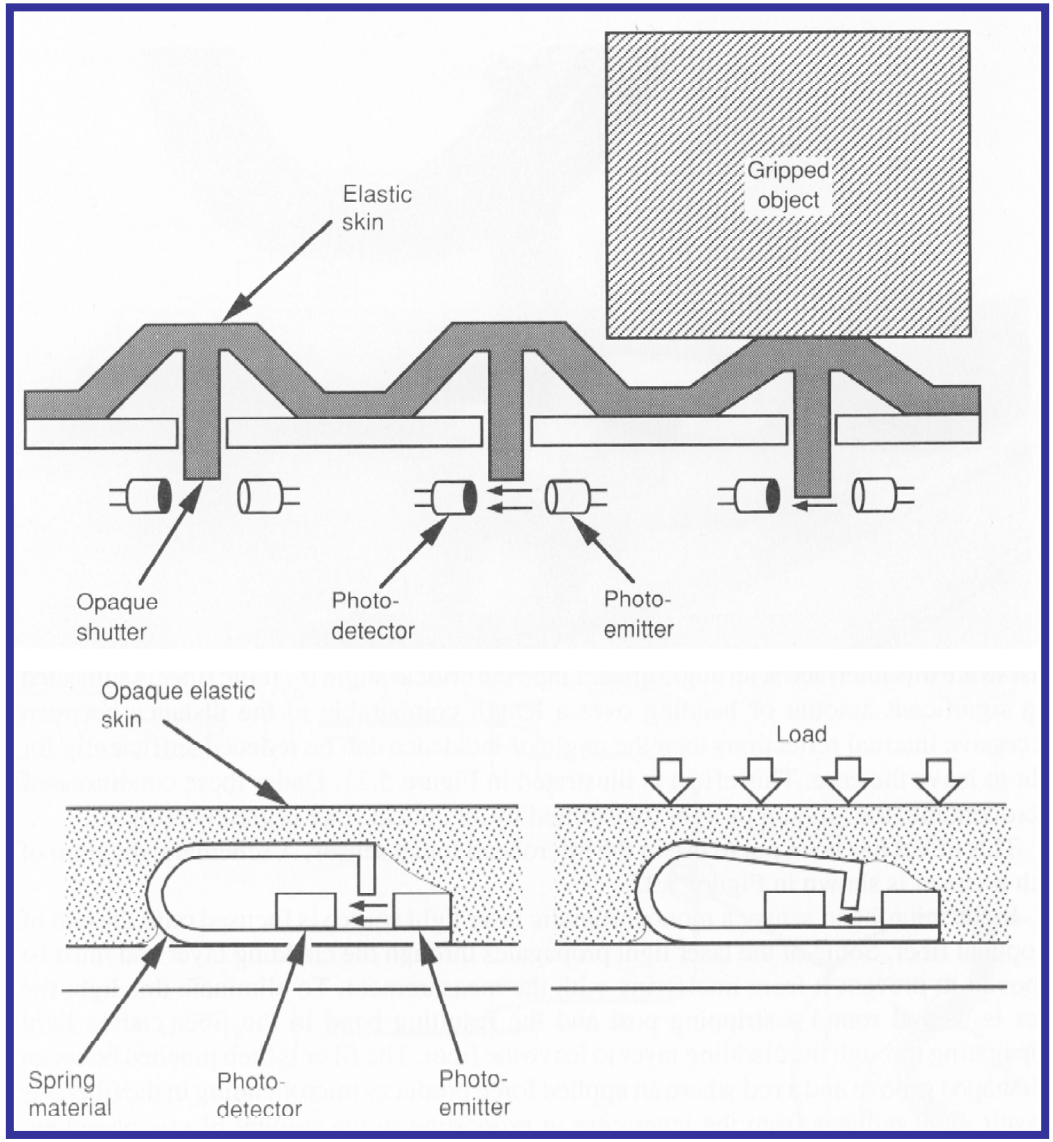
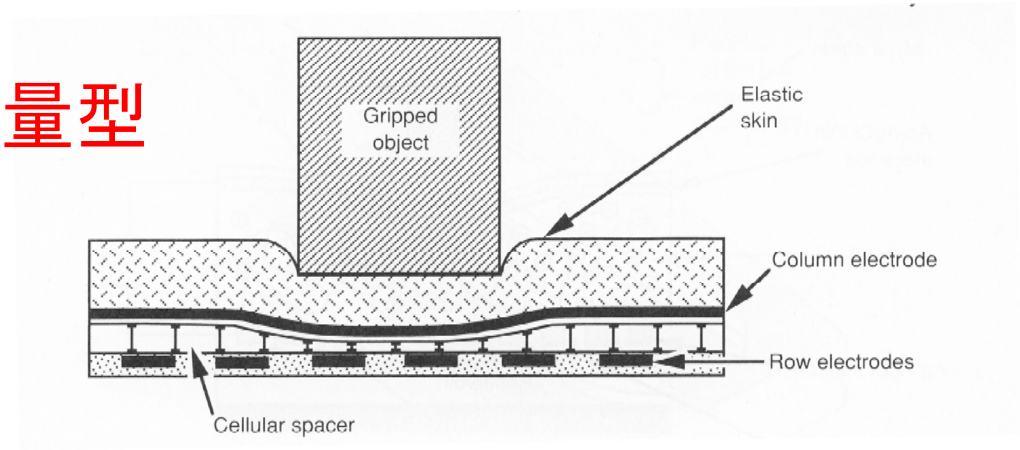
    - 圧覚センサ
    - すべり覚センサ
  - 非接触センサ
    - ビジョンセンサ（視覚）
    - 近接覚センサ

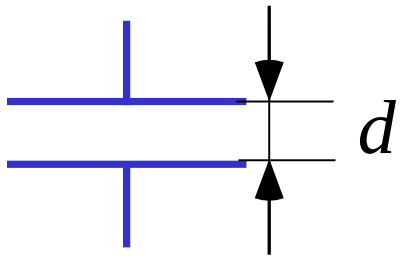

Gripped object
Reflective rubber material
Light guide
Light source
Emerging light
Optical pattern emerging from light guide
To camera
(a) Camera
(b) Photodiode array
(c) Optical fibre

50
100


Gripped object
Elastic skin
Opaque shutter
Photo-detector
Photo-emitter
Opaque elastic skin
Load
Spring material
Photo-detector
Photo-emitter

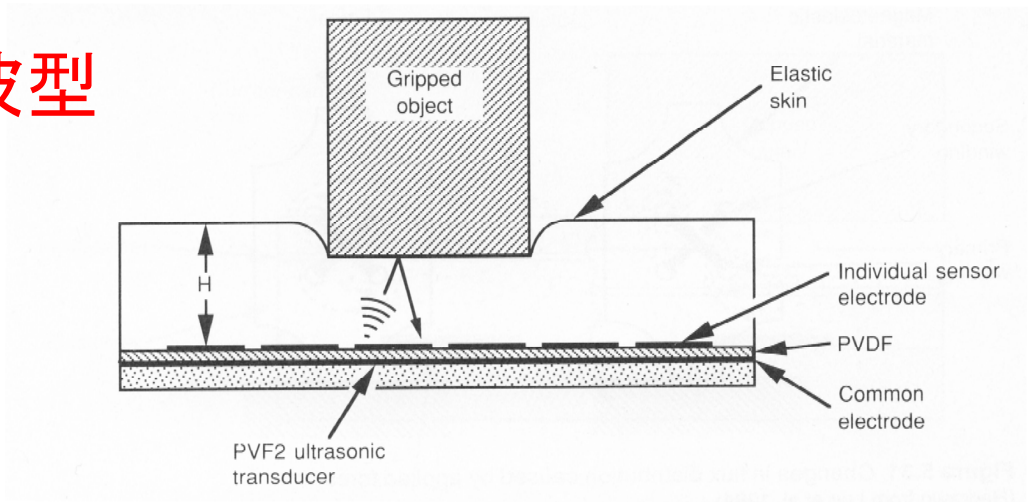
静電容量型




$$C = \varepsilon \frac{S}{d}$$

超音波型



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- 外界センサ
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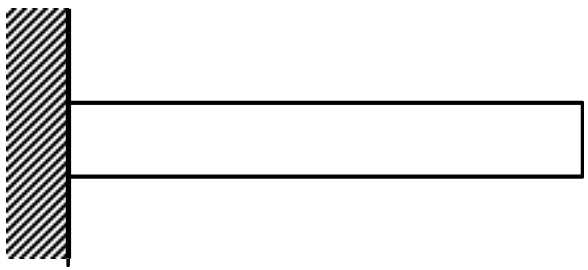
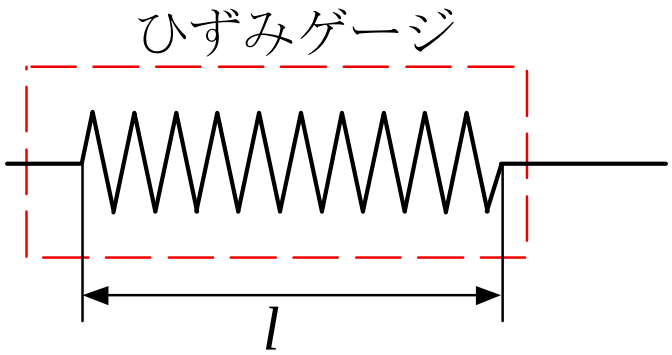
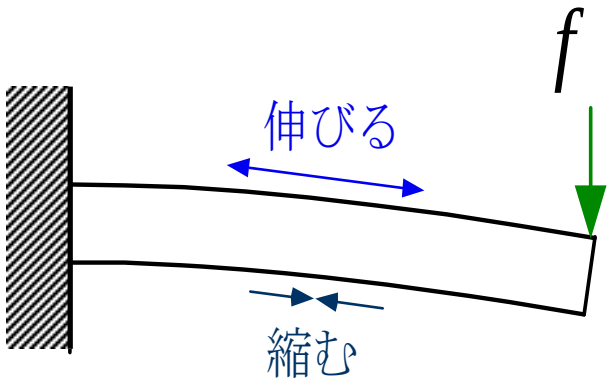
    - 力覚センサ
    - 接触覚センサ
    - 圧覚センサ
    - すべり覚センサ
  - 非接触センサ
    - ビジョンセンサ（視覚）
    - 近接覚センサ

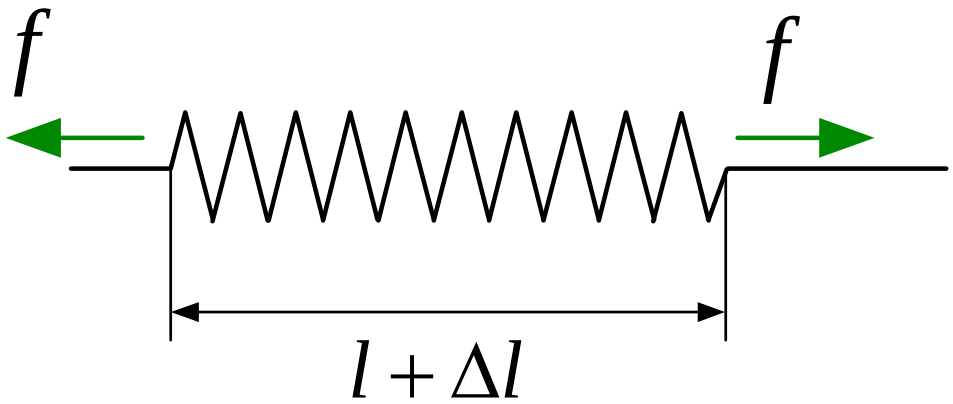
# 力センシング

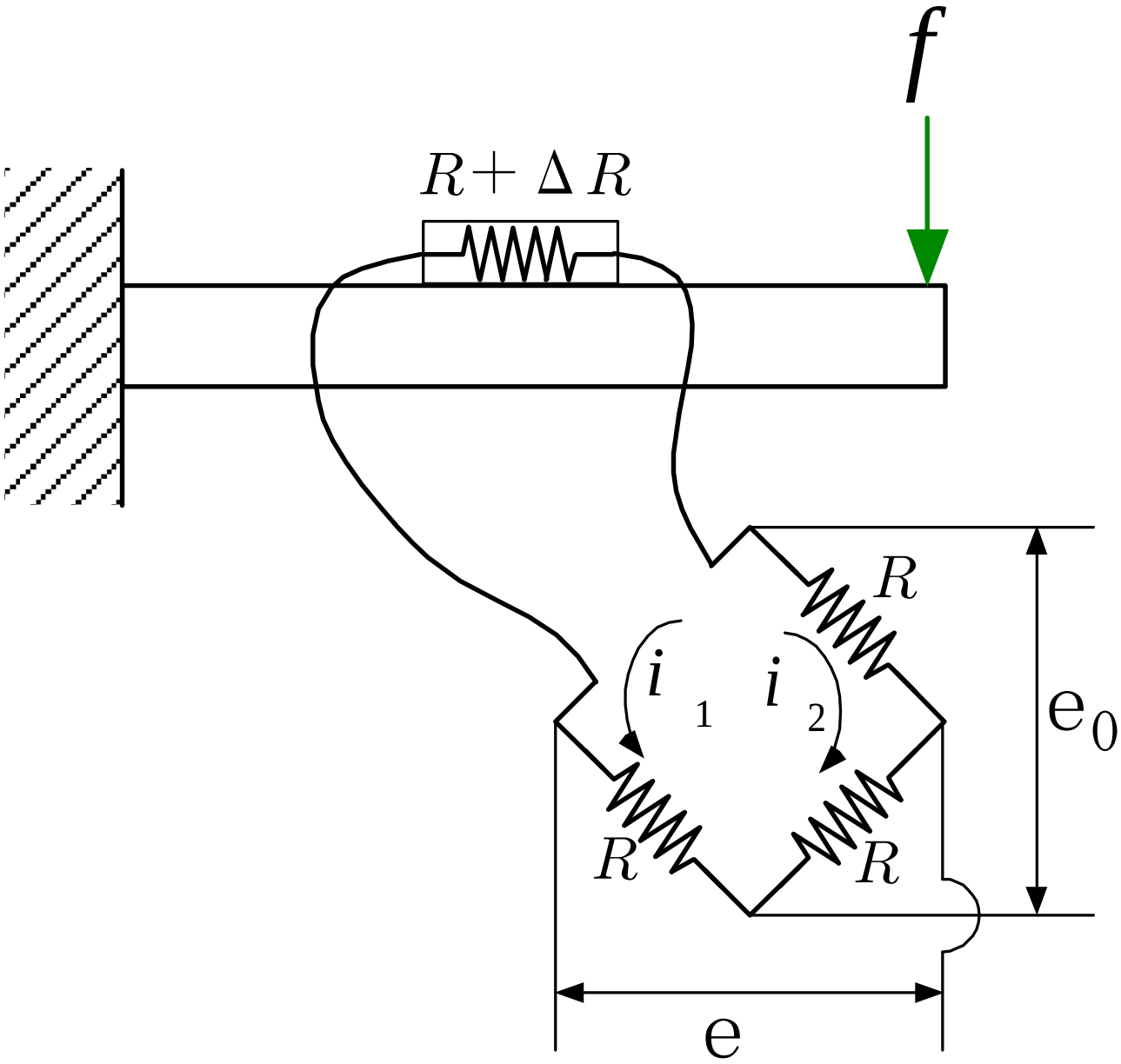
力センシングの基本 → 抵抗の変化を利用






f
R+ΔR
R
i 1
i 2
R
R
e0
e

$x \fallingdotseq 1$ のとき

$$f(x) = f(0) + xf'(0) + \frac{x^2}{2!} f''(0) + \cdots$$

例えば･･･

$$f(x) = \frac{1}{1+x}$$

$$f'(x) = \frac{-1}{(1+x)^2}$$

$$\therefore\ f(0) = 1$$

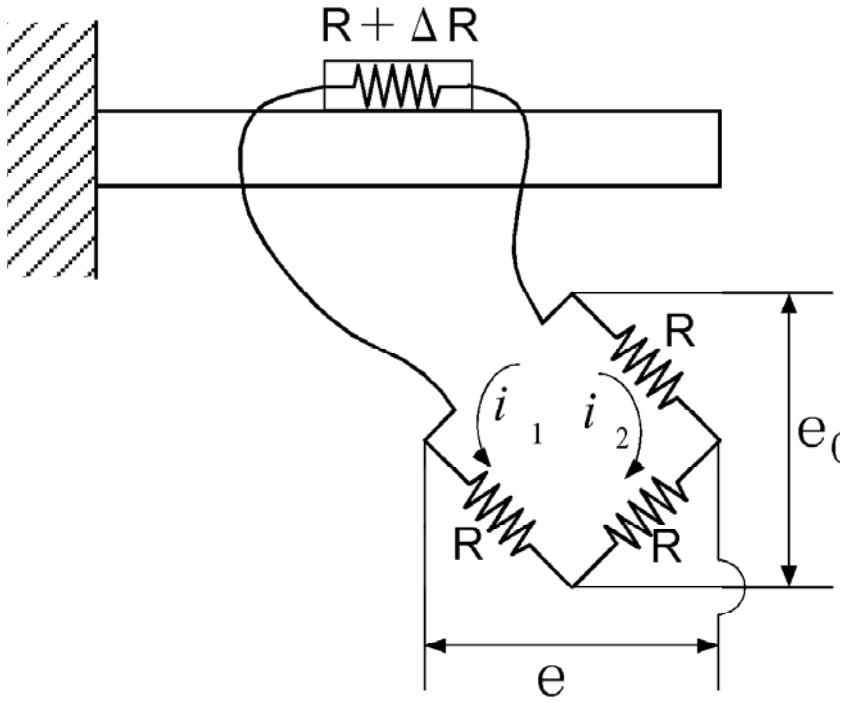
$$f'(0) = -1$$

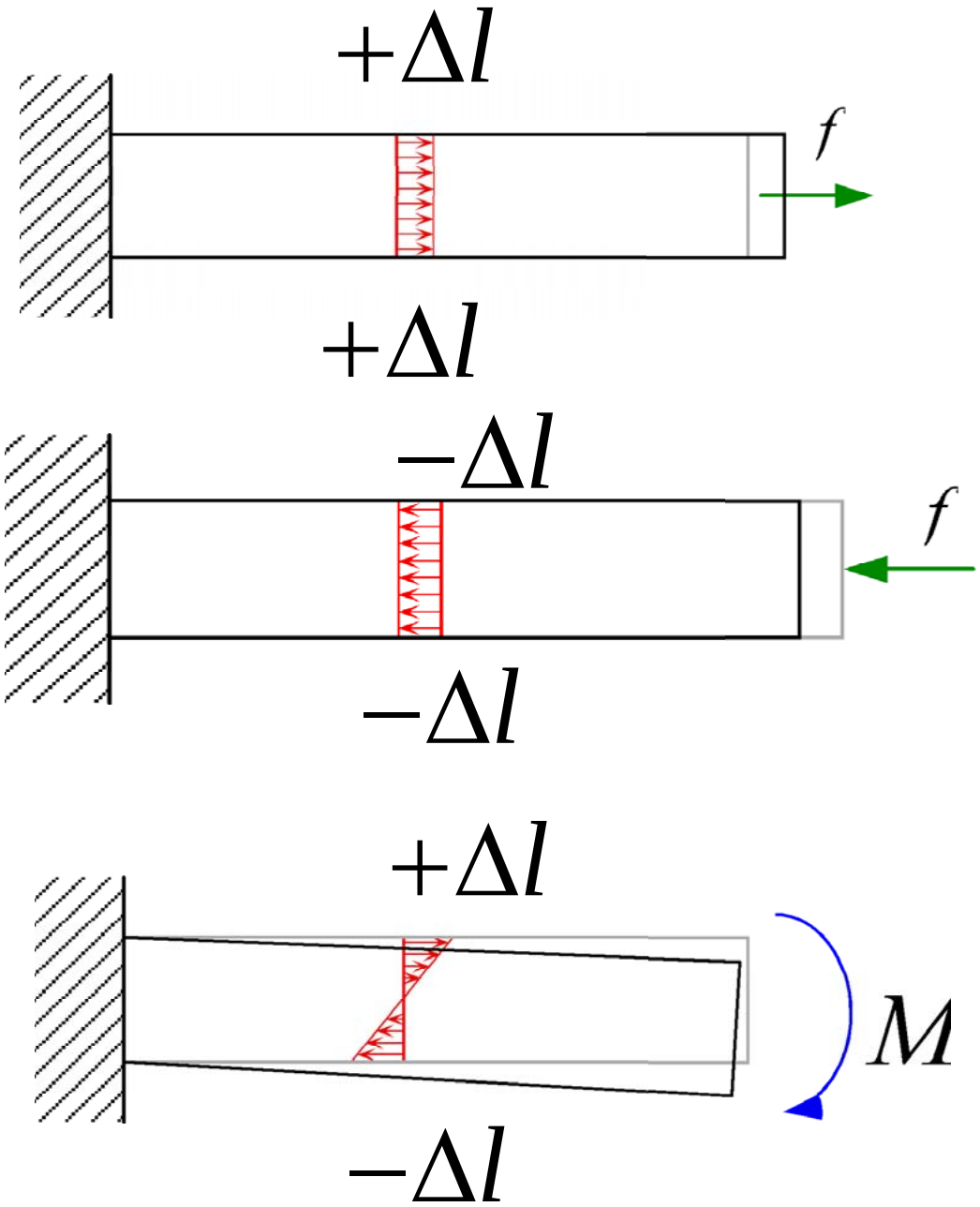
$$f(x) \fallingdotseq f(0) + xf'(0) = 1 - x$$

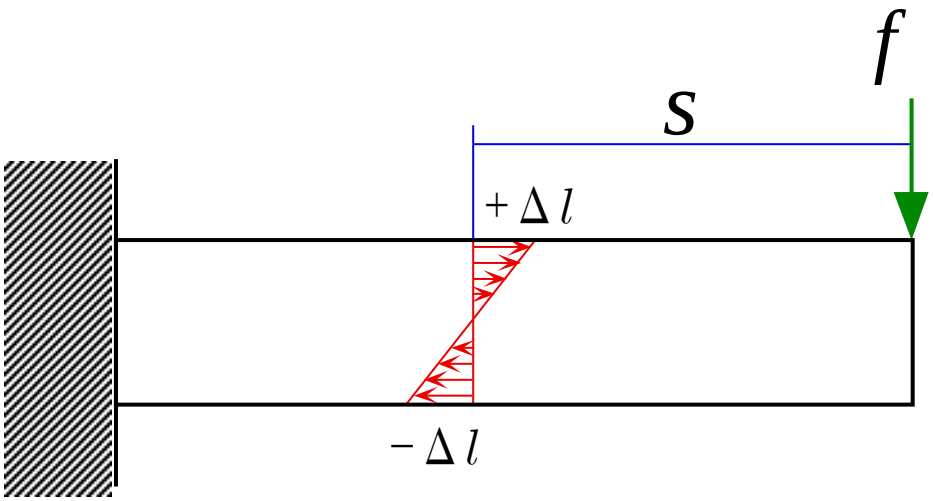
$$-\frac{R}{2R}\left(\frac{1}{1+\frac{\Delta R}{2R}}\right)e_0+\frac{R}{2R}e_0$$

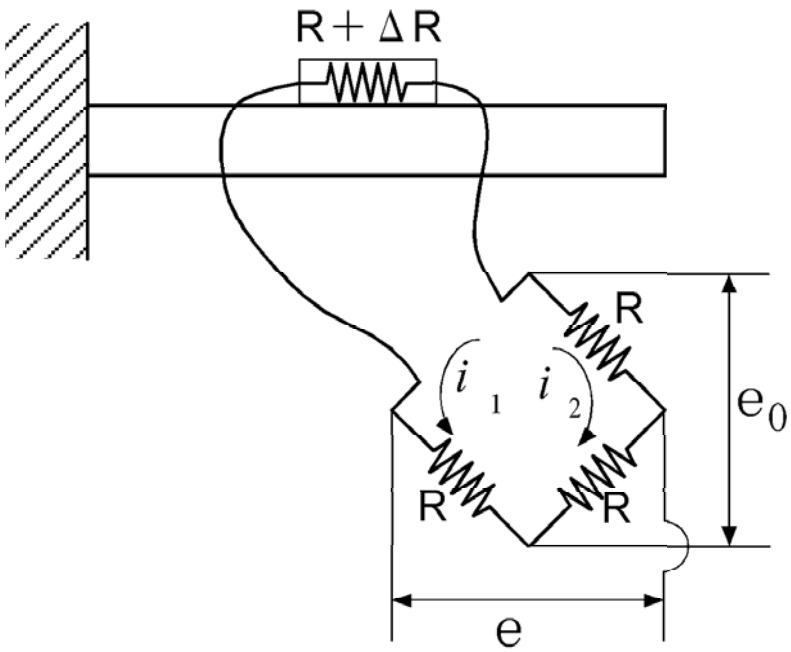
$$\doteqdot -\frac{1}{2}\left(1-\frac{\Delta R}{2R}\right)e_0+\frac{1}{2}e_0$$

$$=\frac{\Delta R}{4R}e_0$$




$+\Delta l$
$f$
$+\Delta l$
$-\Delta l$
$f$
$-\Delta l$
$+\Delta l$
$M$
$-\Delta l$




モーメント= 距離×力

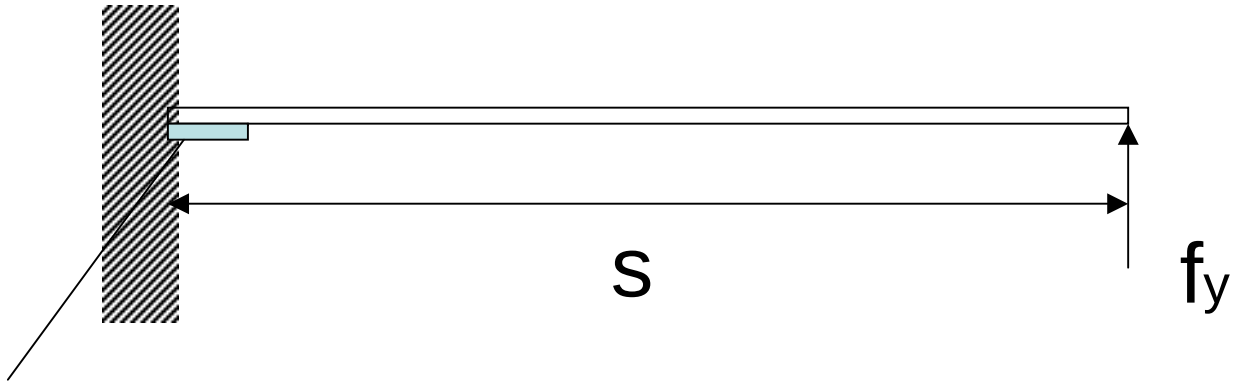
$$\Delta l = cM = csf$$

$$\Delta l \propto \Delta R$$

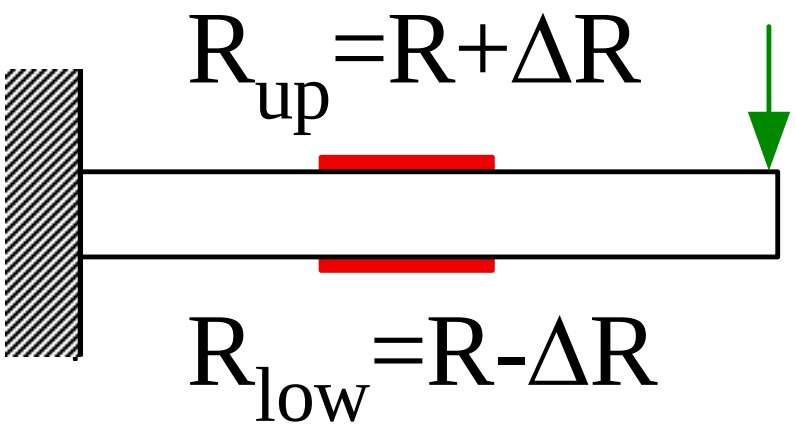
$$e = \frac{\Delta R}{4R} e_0 \propto \Delta l$$

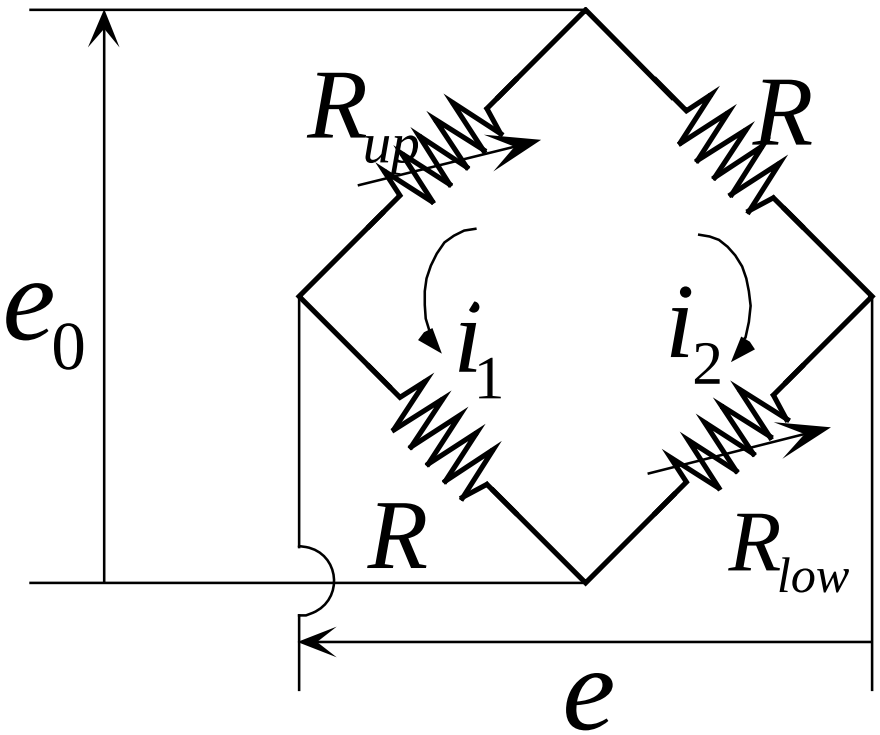
$$\propto f$$

ひずみゲージで
力fに比例した信号がとれる




ひずみゲージ　$e=k\ f_y s$




$$i_1 = \frac{e_0}{2R + \Delta R}$$

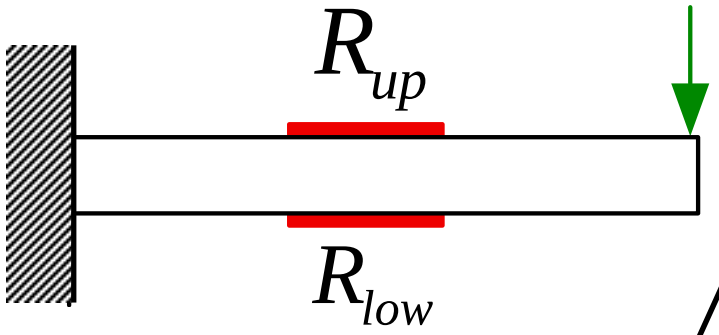
$$i_2 = \frac{e_0}{2R - \Delta R}$$

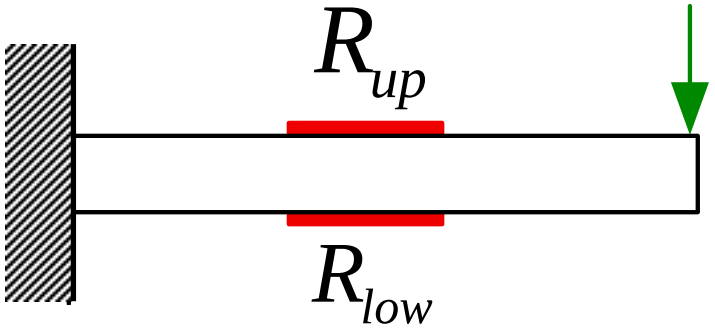
$$e = \frac{-e_0}{2R + \Delta R} R - \left\{ \frac{-e_0}{2R - \Delta R} (R - \Delta R) \right\}$$

$$\fallingdotseq -\frac{e_0}{2}\left(1 - \frac{\Delta R}{2R}\right) + \frac{e_0}{2}\left(1 + \frac{\Delta R}{2R}\right)\left(1 - \frac{\Delta R}{R}\right)$$

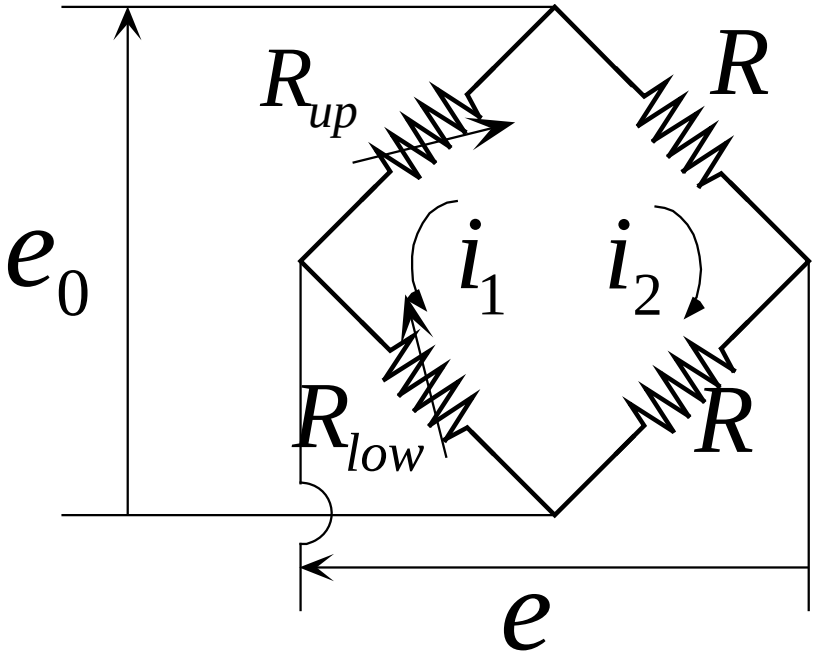
$$\fallingdotseq 0$$

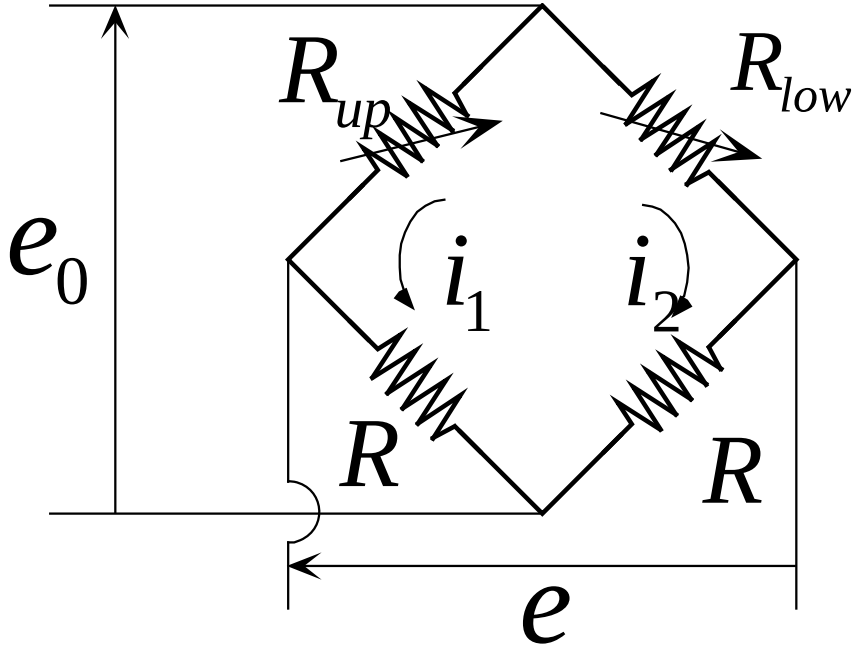
$$\frac{e_0}{2}\left(1 - \frac{\Delta R}{2R}\right)$$

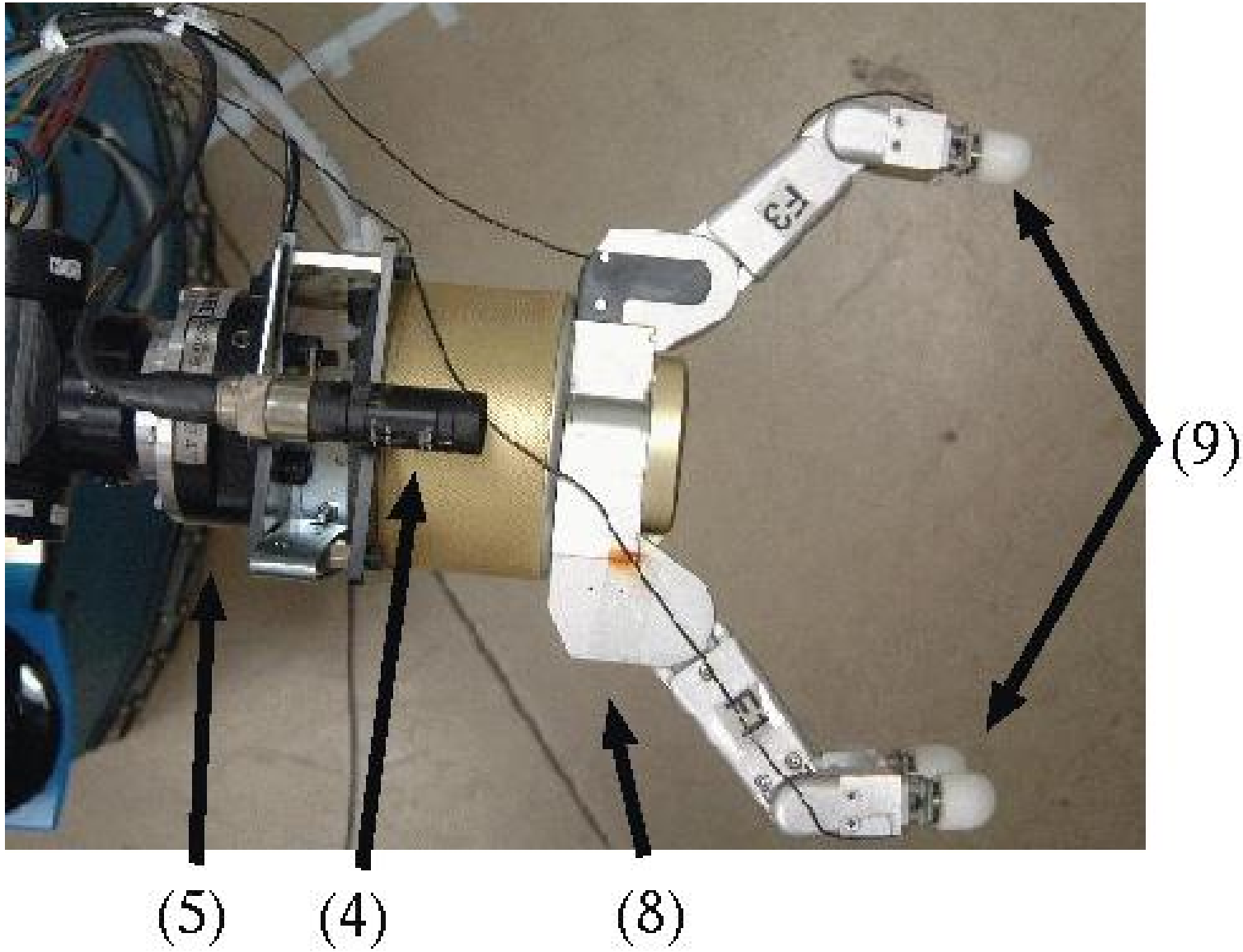


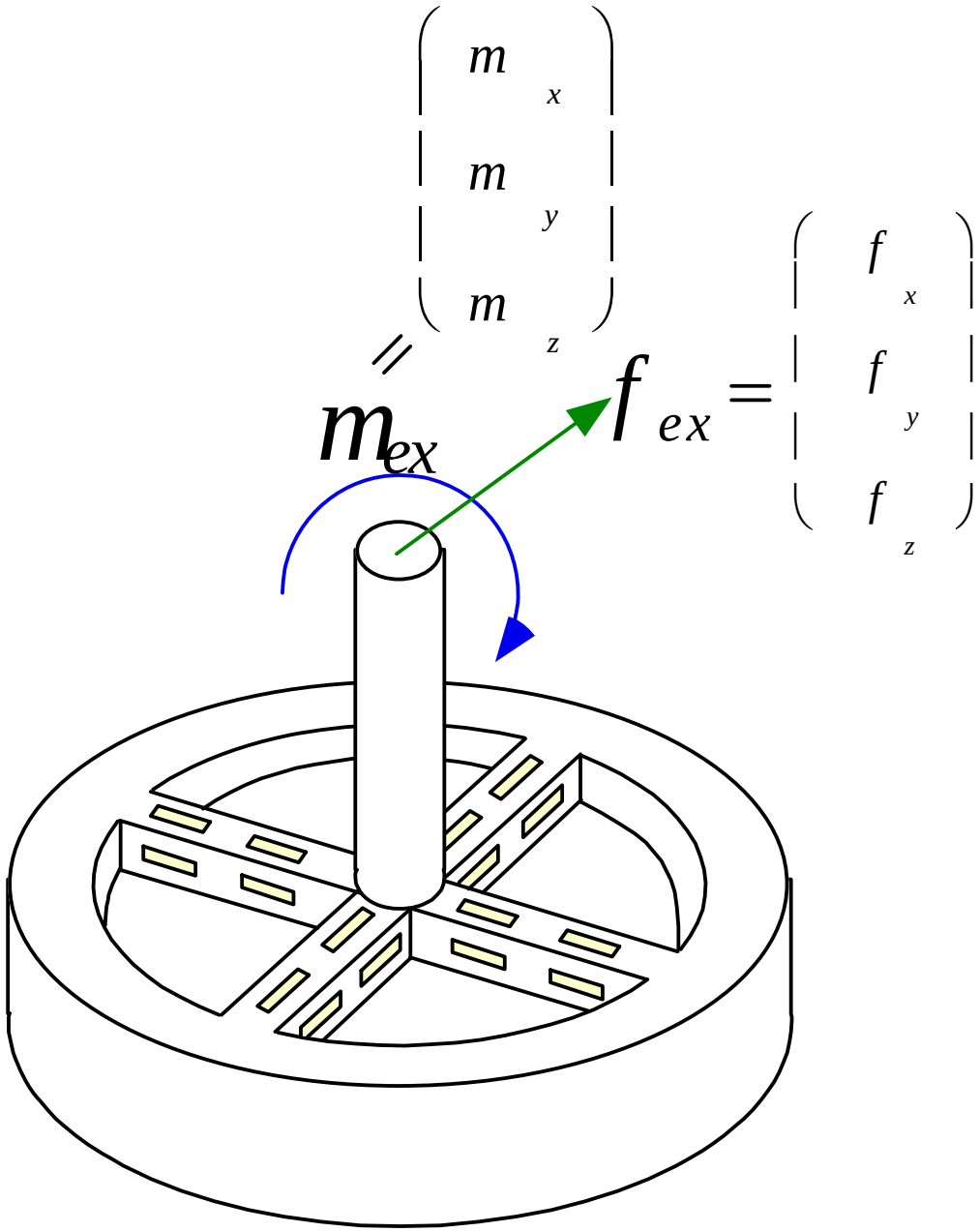

$$e = \frac{\Delta R}{2R} e_0$$



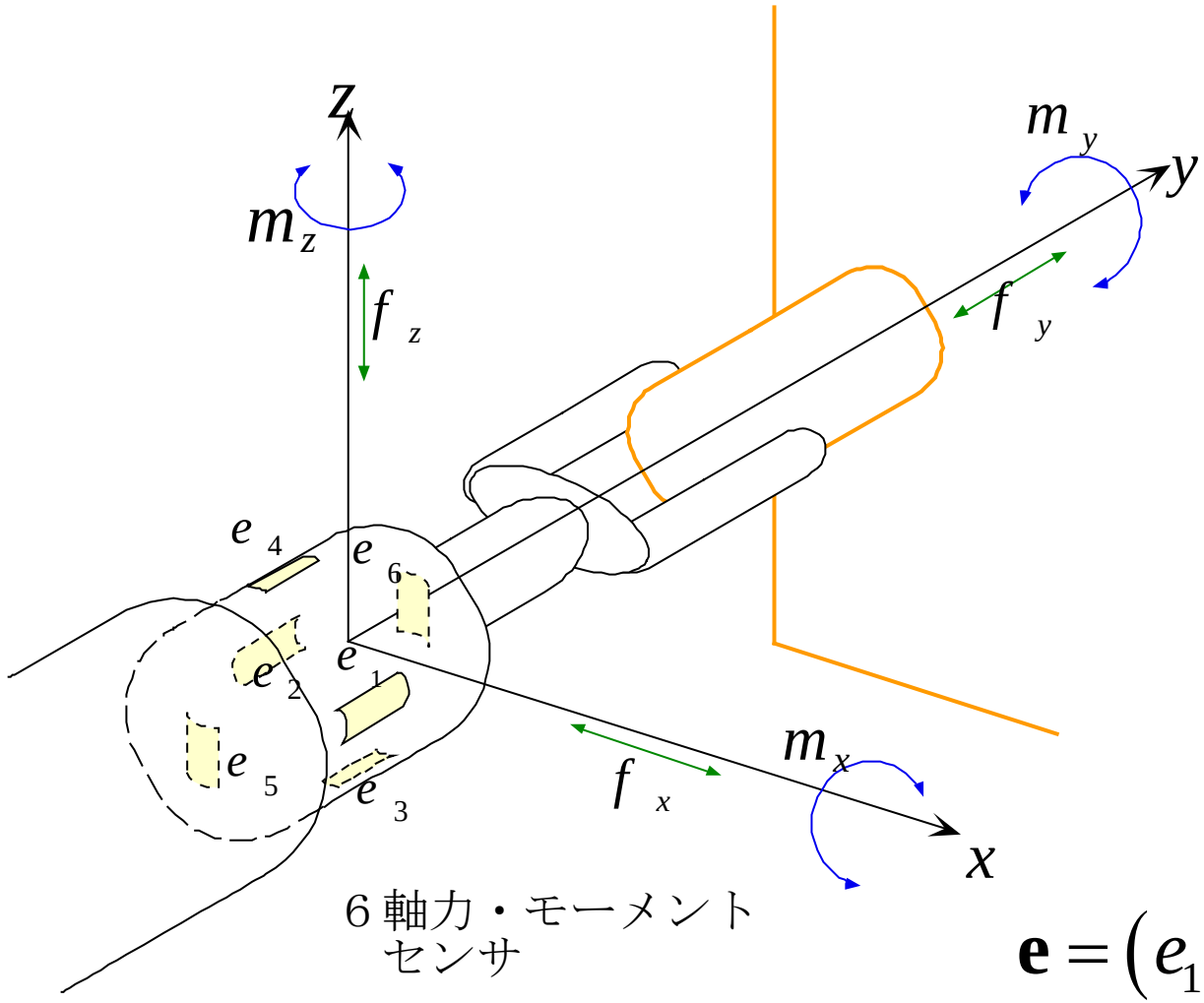




(9)
(5)
(4)
(8)

TRANSDUCER
TYPE
CAP.
S/N


$m_{ex} = \begin{pmatrix} m_x \\ m_y \\ m_z \end{pmatrix}$
$f_{ex} = \begin{pmatrix} f_x \\ f_y \\ f_z \end{pmatrix}$

6軸力センサの一例




# 6軸力･モーメントセンサ

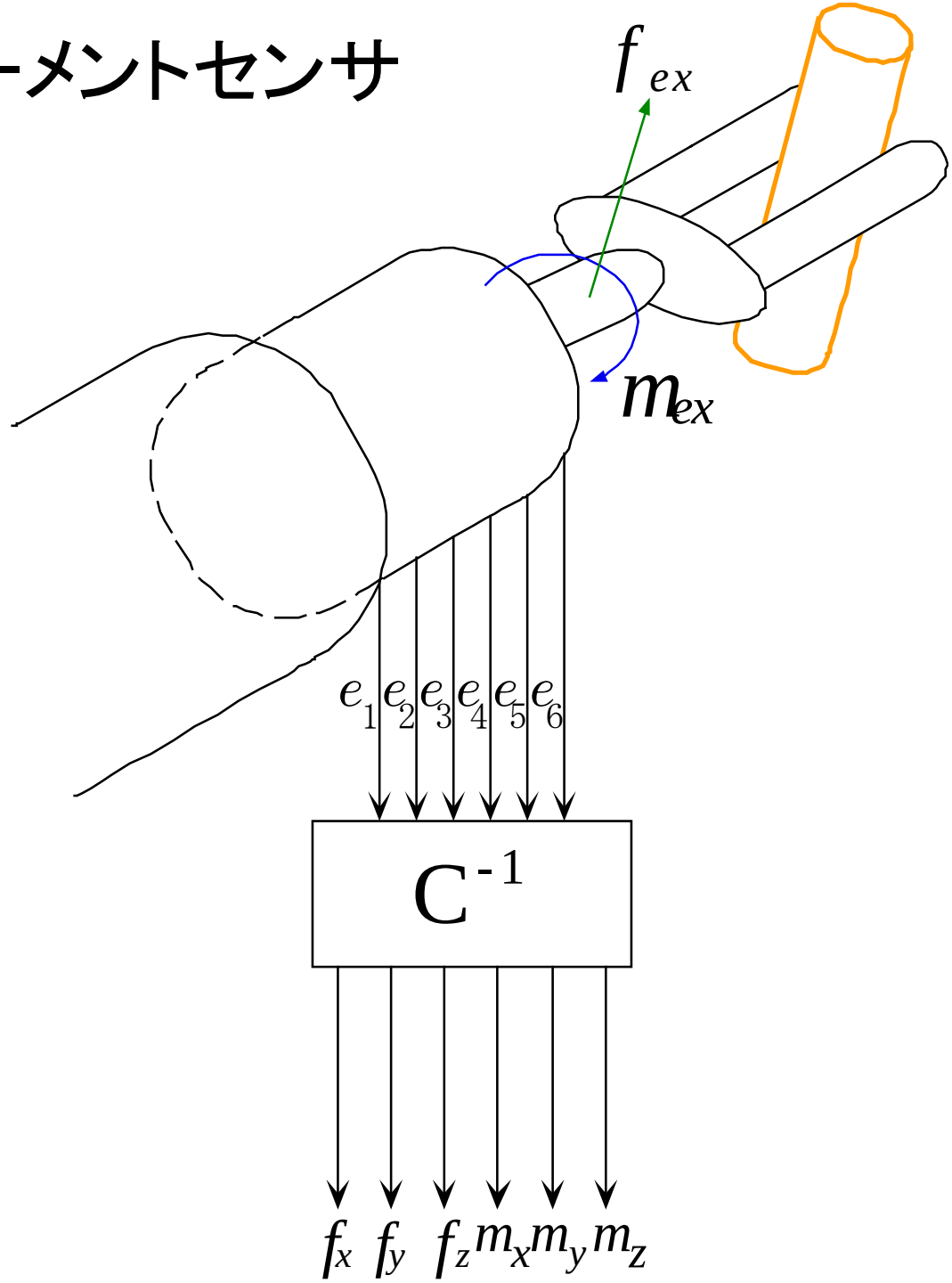
$$\mathbf{e} = \left(e_1, e_2, e_3, e_4, e_5, e_6\right)^T$$

$$\mathbf{F} = \left(f_x, f_y, f_z, m_x, m_y, m_z\right)^T$$

$$\boxed{\mathbf{e} = C\mathbf{F}}$$

$$\mathbf{F} = C^{-1}\mathbf{e}$$

# 6軸力･モーメントセンサ



$$\mathbf{e} = C\mathbf{F}$$

$C$ はどのようにして決める?

$$\begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{16} \\ c_{21} & \cdots & \cdots & c_{26} \\ \vdots & & & \vdots \\ & & & \\ \vdots & & & \vdots \\ c_{61} & \cdots & \cdots & c_{66} \end{pmatrix} \begin{pmatrix} f_x \\ f_y \\ f_z \\ m_x \\ m_y \\ m_z \end{pmatrix}$$

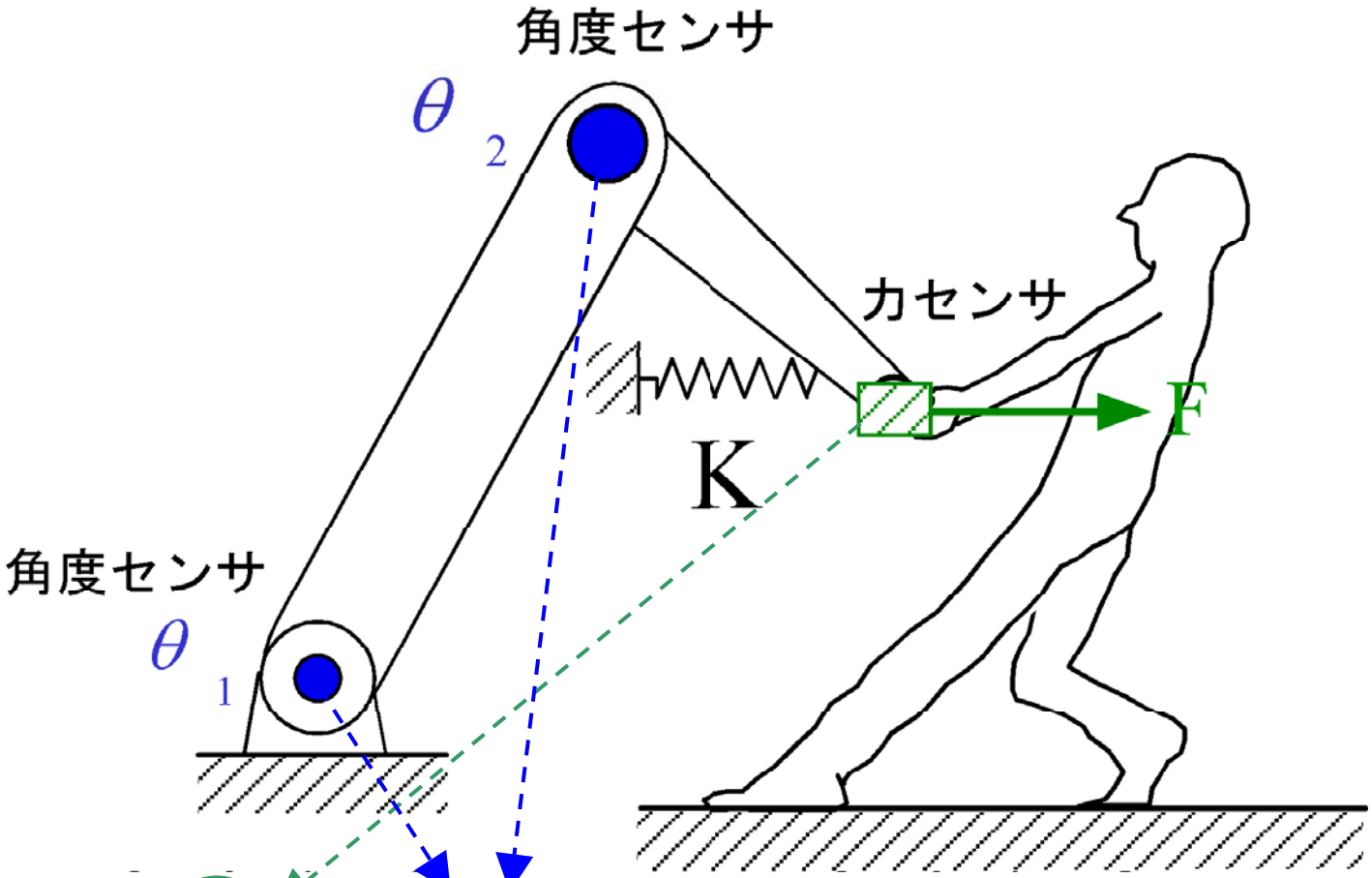
if $f_x = 1, f_y = f_z = m_x = m_y = m_z = 0$

$C$ を決める予備実験

センサを
キャリブレーションするという

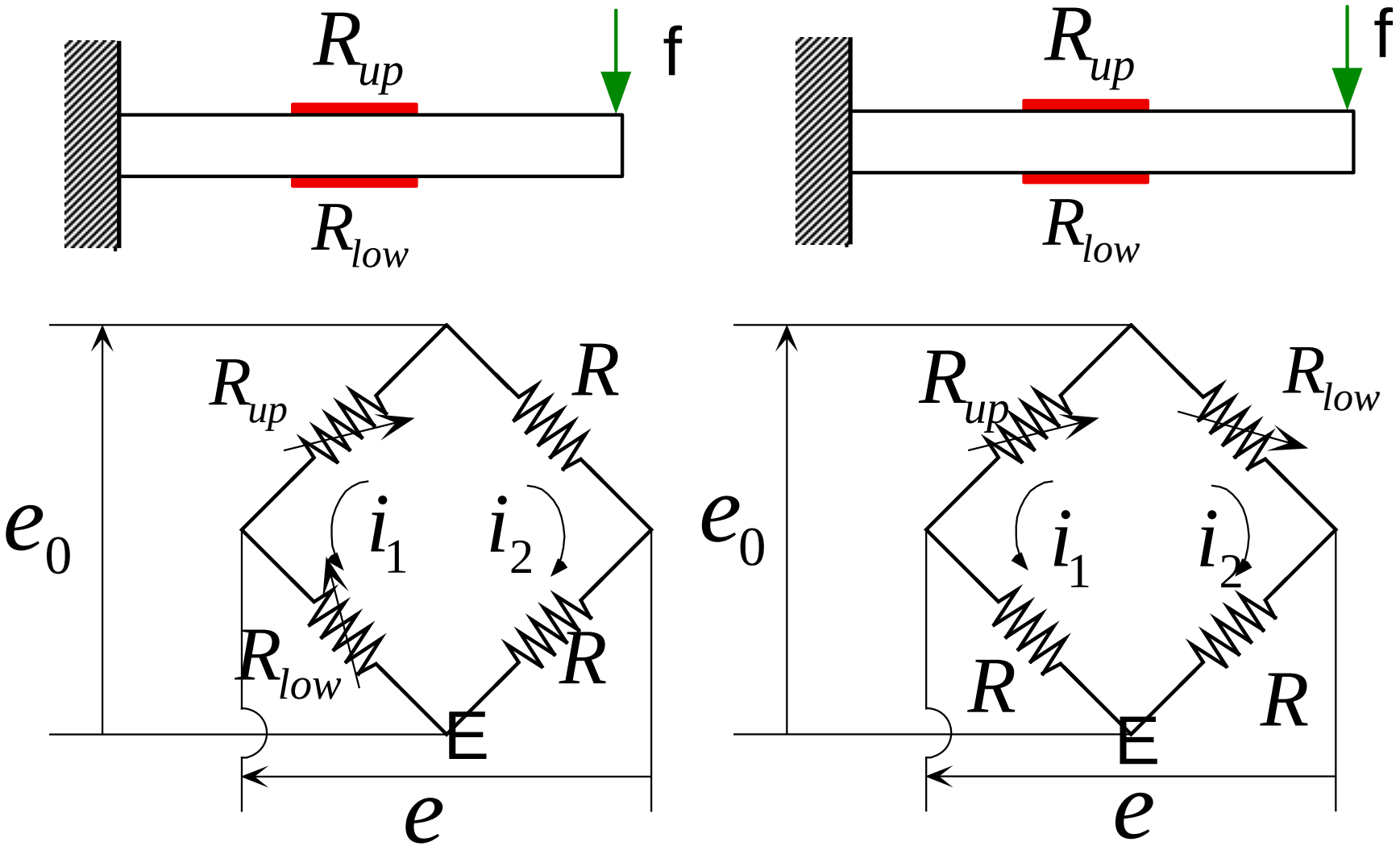
$$\begin{pmatrix} e_1^{(1)} \\ e_2^{(2)} \\ e_3^{(3)} \\ e_4^{(4)} \\ e_5^{(5)} \\ e_6^{(6)} \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{16} \\ c_{21} & \cdots & \cdots & c_{26} \\ \vdots & & & \vdots \\ & & & \\ \vdots & & & \vdots \\ c_{61} & \cdots & \cdots & c_{66} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$$e_1^{(1)} = c_{11}, e_2^{(2)} = c_{21}, \cdots, e_6^{(6)} = c_{61}$$

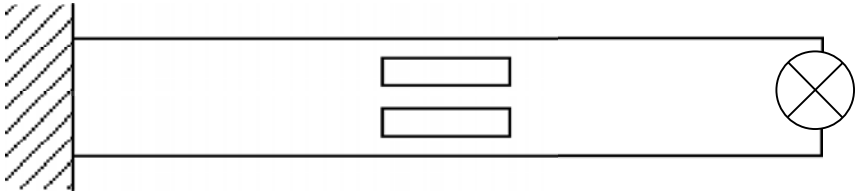



$$F = K\Delta x$$

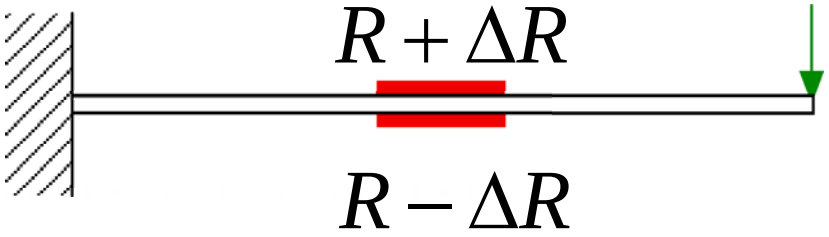
演習問題3：ひずみゲージを弾性板の上下に貼った場合の各ブリッジ出力eを求めよ．ただしEはアース点とし，Rup=R+ΔR，Rlow=R-ΔR，（R>> ΔR）とする．



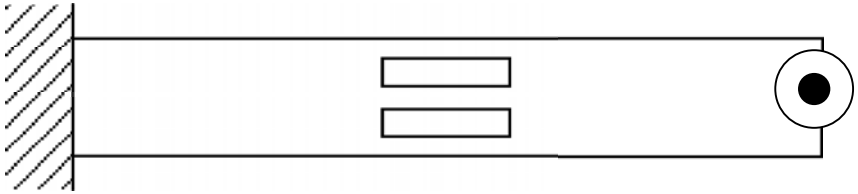
問題3のひずみゲージを上面に2枚，下面に2枚貼った場合



上面



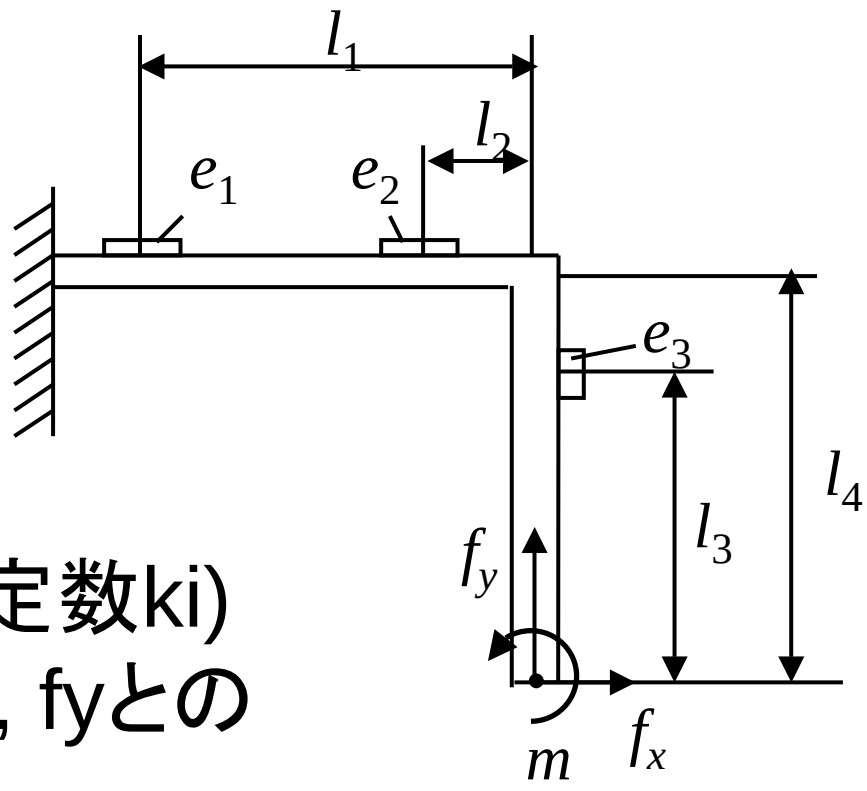

側面



下面

課題4

3軸力センサに対して
下記の問いに答えよ.



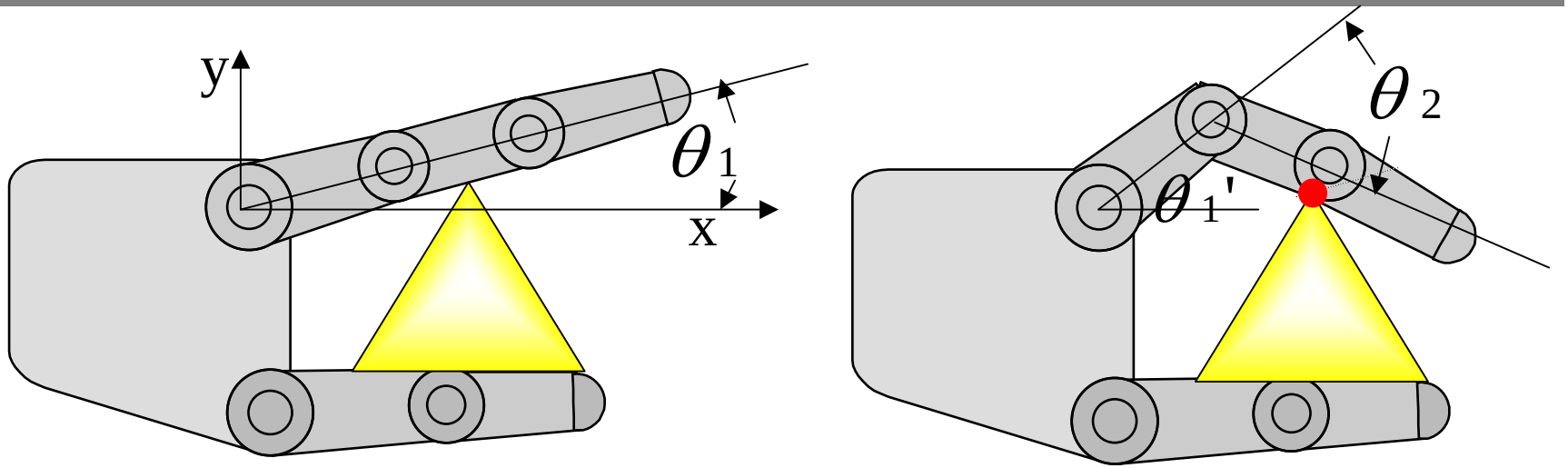

(1)eiがその点にかかる
モーメントに比例（比例定数ki)
するものとしてeiとm, fx, fyとの
関係を求めよ.

(2)e=Cfの関係を行列で標記
せよ.

(3)ki=1, 幾何学パラメータが
右記で与えられる場合のCの
逆行列を求めよ.

$l_1 = 2[\mathrm{m}]$
$l_2 = 1[\mathrm{m}]$
$l_3 = 1[\mathrm{m}]$
$l_4 = 2[\mathrm{m}]$

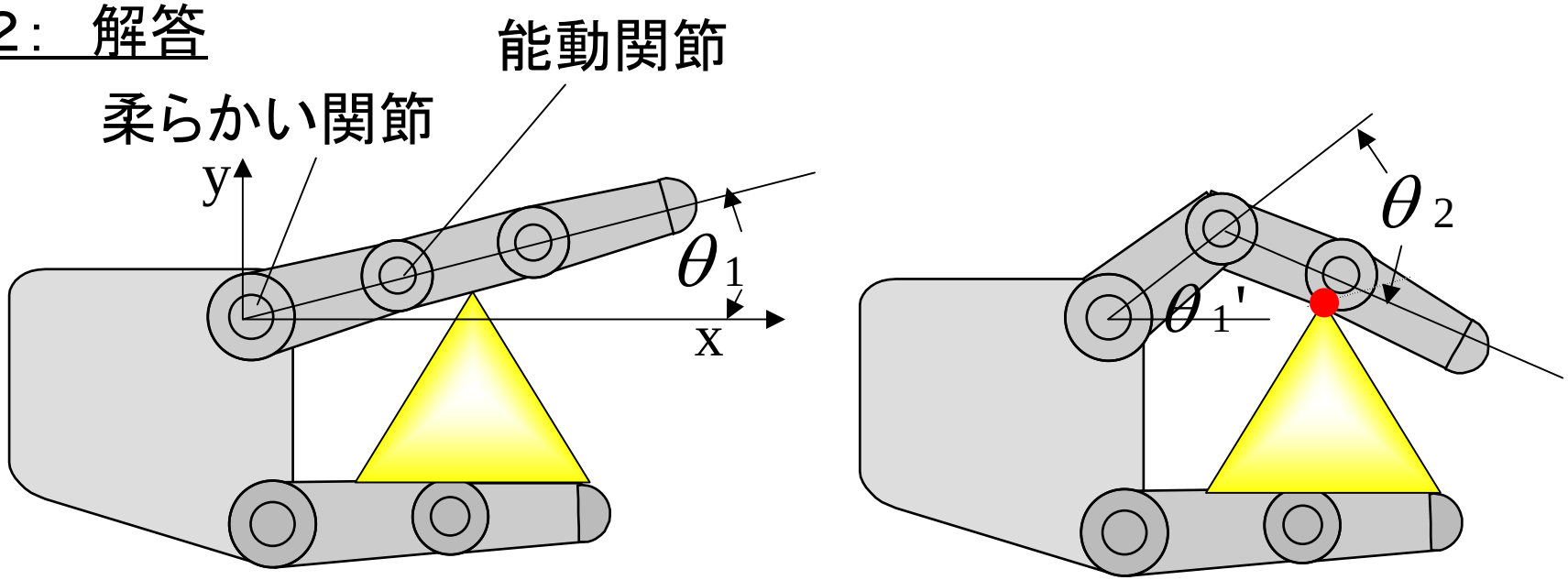
# 課題2：柔軟関節と能動関節を組み合わせた触覚センシングについて以下の問いに答えよ.




(1)どの関節を柔らかくして，どの関節を能動関節に選べばこのような動作が実現できるか.

(2)ハンドの幅を無視して，接触点位置を求めよ．ただし，関節角度は測れるものとし，各リンクの長はそれぞれ1.0[m]とする.

# 課題2： 解答




(1)どの関節を柔らかくして，どの関節を能動関節に選べばこのような動作が実現できるか．左図参照

(2)ハンドの幅を無視して，接触点位置を求めよ．ただし，関節角度は測れるものとし，各リンクの長はそれぞれ1.0[m]とする．

$$y=\tan\theta_1\ x$$

$$y=\tan(\theta'_1-\theta_2)\ (x-\cos\theta'_1)+\sin\theta'_1$$

上記二式の交点を求めればよい．