3.13 What is a potential

P is a potential:
This sentence implies many consequences for the function P:

- $\vec{x}$ describes the location (state)
- The value of P does not depend on the path (i.e. on the history of the system)
- The value only depends on the coordinates (the state); differences between states are independent of the path between them:
$$P(\vec{x}_2) - P(\vec{x}_1) = \int_1^2 \vec{\nabla} P d\vec{x} \quad , \tag{3.28}$$
- dP is a total differential:
$$dP = \vec{\nabla} P d\vec{x} = \frac{\partial P}{\partial x_1} dx_1 + \frac{\partial P}{\partial x_2} dx_2 + \frac{\partial P}{\partial x_3} dx_3 \quad , \tag{3.29}$$
i.e. the change of the coordinates defines completely the change of P.
- The "force" follows from the gradient
$$-\vec{\nabla} P \quad . \tag{3.30}$$

We will illustrate these relations for the example of an electric potential $W_e(\vec{x})$:

- $$\vec{E} = -\vec{\nabla} W_e(\vec{x}) \quad , \quad W_e(\vec{x}_2) - W_e(\vec{x}_1) = -\int_1^2 \vec{E} d\vec{r} \quad , \quad \begin{matrix} dW_e & = & -\vec{E} d\vec{r} \\ \text{scalar} & & \text{vector} \\ \text{energy} & & \text{force} \end{matrix} \tag{3.31}$$
- **Consequences for measurements:**
  - Measure forces E_i in all directions x_i at each position $\vec{x}$.
  - Calculate $dW_i = -E_i dx_i$ for the vector components along the path.
  - The overall work is $dW = \sum_i dW_i$. This does not depend on the sequence of the measurements of the electric fields (forces).
  - This procedure needs a lot of single measurements for the three directions at each position along the path.
- Direct measurement of the potential difference
  - just one measurement
- Both procedures are equivalent and you may switch between them, depending on which quantity is easier to measure.
- Just knowing that a function is a potential makes "life" much easier, even if you want to measure forces:
  - "Search for the easiest path from A to B on which you can sum up the forces to calculate the potential difference".