

The Seven Wonders of the World

Exercises

Updated 16 January 2025

Contents

1	Physics, quantities, units	4
1.1	.....	4
1.2	.....	4
1.3	.....	4
1.4	.....	5
1.5	.....	6
1.6	.....	6
	Example solutions	9
2	Time and space	12
3	Volume contents, fluxes, supplies	13
4	Physical laws	14
5	The Seven Wonders of the world	15
6	Conservation & balances of matter	16
7	Conservation of electric charge	17
8	Conservation of magnetic flux	18
9	Balance of momentum	19
10	Balance of energy	20
11	Balance of angular momentum	21
12	Remarks on momentum and energy	22

13 Balance of entropy	23
14 Constitutive relations	24

Physics, quantities, units

1

For some of the following exercises you can refer to tables [1.1](#) and [1.2](#) on page 8 (reproduced from the textbook).

1.1

Preferably together with a friend or colleague:

If you have some large-language-model service (such as ChatGPT), ask it which physical laws are universally valid in Newtonian Mechanics and in General Relativity and in Thermodynamics and in Chemistry and in Electromagnetics.

Discuss the answer you get, based on what you have learned so far. (Note: if the answer mention a ‘balance of boost momentum’, that’s actually correct.)

Argue with the LLM and see where the discussion goes.

1.2

Take *time* and *velocity* as primitive quantities.

1. Try to define *distance* as a derived quantity
2. Try to define *acceleration* as a derived quantity.

1.3

Which of the following quantities are *scalars*, and which are *vectors*?

- Time
- Distance
- Position

- Energy
- Velocity
- Speed
- Momentum
- Entropy
- Angular momentum
- Force
- Temperature
- Magnetic flux
- Electric charge
- Electric current
- Heat
- Power
- Volume
- Pressure

1.4

Find the correct units for the following quantities:

- *Volumic energy* or *energy density*, defined as energy divided by volume
- *Energy flux*, defined as energy divided by time.
- *Power*, defined as energy divided by time.
- *Heating*, defined as energy divided by time.
- *Magnetic flux*, which we take as a primitive quantity.
- *Electric potential difference*, defined as magnetic flux divided by time.
- *Force*, defined as momentum divided by time.
- *Momentum flux*, defined as momentum divided by time.
- *Momentum supply*, defined as momentum divided by time.
- *Pressure*, defined as force divided by area.
- *Amount of substance (or of matter)*, which we take as primitive.
- *Molar mass*, defined as mass divided by amount of substance.
- *Specific momentum*, defined as momentum divided by mass.
- *Volumic charge* or *charge density*, defined as charge divided by volume.
- *Entropy*, which we take as primitive, has dimension of energy divided by temperature.
- *Matter density*, defined as amount of substance divided by volume.
- *Matter flux*, defined as amount of substance divided by time.

1.5

With a friend or colleague:

1. Try to explain to your friend the difference between a *primitive quantity* and a *derived quantity*; then let your friend criticize unclear or incorrect points in your explanation, and comment on the good points. Then invert your roles: your friend tries to explain to you, and you criticize and comment.
2. Similarly as the previous exercise, but explaining the difference between a *scalar quantity* and a *vector quantity*.
3. If you have some large-language-model service (such as ChatGPT), ask it to explain the difference between primitive and derived quantity, and between scalar and vector quantity. Find out weak or unsure points in its answer, given what you've learned so far.

1.6

Find which of the following mathematical expressions and equalities are dimensionally incorrect, and explain why they are incorrect:

- ▷ $11 \text{ J} + 4 \text{ kg}$
- ▷ $\tan\left(\frac{a}{b}\right)$, where a has dimension length and b has dimension time
- ▷ $299\,792\,458 \text{ m/s}$
- ▷ $\exp\left(\frac{71 \text{ s}}{3 \text{ s}}\right)$
- ▷ $\cos(3.14) \text{ m}$
- ▷ $m - v$, where m has dimension of mass and v of velocity
- ▷ $10 \text{ N s} - 2 \text{ kg m/s} = 8 \text{ J s/m}$
- ▷ $\exp(-8 \text{ J})$
- ▷ $(9 \text{ m}, 0.1 \text{ rad}, -0.5 \text{ rad})$
- ▷ $8 \text{ J/s} = 12 \text{ N m} - 4 \text{ N m}$

- ▷ $e^{-8} \text{ J}$
- ▷ $\frac{15 \text{ J}}{5 \text{ kg/s}^2} = 3 \text{ m}^2$
- ▷ $\sqrt{25} \text{ K} = 5$
- ▷ $(e^7)^s$
- ▷ $\tan\left(\frac{10 \text{ m}}{5 \text{ m}}\right)$
- ▷ $\sqrt{300} \text{ K}$
- ▷ $\sin(t/\text{s})$, where t has dimension of time
- ▷ $\frac{3}{\text{s}}$
- ▷ $\sin(10 \text{ s})$

Quantity	SI Dimension	Unit
Time	time	<i>second</i> s
Length	length	<i>metre</i> m
Temperature	temperature	<i>kelvin</i> K
Matter	amount of substance	<i>mole</i> mol
Electric charge	electric charge	<i>coulomb</i> C
Magnetic flux	magnetic flux	<i>weber</i> Wb
Energy	energy, mass	<i>joule</i> J, <i>kilogram</i> kg
Momentum	force · time, mass · length/time, energy · time/length	N · s, kg · m/s, J · s/m
Angular momentum	force · length · time, mass · length ² /time, energy · time	N · m · s, kg · m ² /s, J · s
Entropy	energy/temperature	J/K

Table 1.1 Dimensions and units of the main physical quantities used in these notes. Their fluxes have the dimensions divided by time, and therefore units divided by seconds. Quantities in **boldface** are vectors, the others are scalars.

Quantity	Volume content [unit]	Flux [unit]
matter	N [mol]	J [mol/s]
electric charge	Q [C]	\mathcal{I} [C/s or A]
magnetic flux	\mathcal{B} [Wb]	\mathcal{E} [Wb/s or V]
energy	E [J]	Φ [J/s or W]
momentum	\mathbf{P} [N s]	\mathbf{F} [N]
angular momentum	\mathbf{L} [N m s]	$\boldsymbol{\tau}$ [N m]
entropy	S [J/K]	Π [J/(K s)]

Table 1.2 Units for volume contents and fluxes of the main seven quantities.

Example solutions

1.2

1. “Distance is the product of a time lapse and a particular velocity”. See section 2.3 about *Radar distance* in the main text.
2. “Acceleration is the ratio between a change in the product of a time lapse and a particular velocity, and the time taken by that change”.

1.3

These quantities are scalars:

- Time
- Distance
- Energy
- Speed
- Entropy
- Temperature
- Magnetic flux
- Electric charge
- Electric current
- Heat
- Power
- Volume

These quantities are vectors:

- Position
- Velocity
- Momentum
- Angular momentum
- Force

For *pressure*, it depends on the context. In some applications it is considered a scalar, but in other applications it is considered a vector – or actually a generalized kind of vector, called *tensor*, which can be represented by a matrix.

1.4

- *Volumic energy*: J/m^3

- *Energy flux*: J/s
- *Power*: J/s
- *Heating*: J/s
- *Magnetic flux*: Wb
- *Electric potential difference*: Wb/s
- *Force*: N
- *Momentum flux*: N
- *Momentum supply*: N
- *Pressure*: N/m²
- *Amount of substance*: mol
- *Molar mass*: kg/mol
- *Specific momentum*: N · s/kg \equiv m/s
- *Volumic charge*: C/m³
- *Entropy*: J/K
- *Matter density*: mol/m³
- *Matter flux*: mol/s

1.6

- ▷ 11 J + 4 kg
Incorrect: cannot sum quantities of different dimension
- ▷ $\tan\left(\frac{a}{b}\right)$, where a dimension length and b has dimension time
Incorrect: trigonometric function must have a dimensionless argument, but a/b has dimension length/time
- ▷ 299 792 458 m/s
- ▷ $\exp\left(\frac{71 \text{ s}}{3 \text{ s}}\right)$
- ▷ $\cos(3.14) \text{ m}$
- ▷ $m - v$, where m has dimension of mass and v of velocity
Incorrect: cannot subtract quantities of different dimension
- ▷ $10 \text{ N s} - 2 \text{ kg m/s} = 8 \text{ J s/m}$
- ▷ $\exp(-8 \text{ J})$
Incorrect: exponential function must have a dimensionless argument, but this argument has dimension energy

▷ $(9 \text{ m}, 0.1 \text{ rad}, -0.5 \text{ rad})$

▷ $8 \text{ J/s} = 12 \text{ N m} - 4 \text{ N m}$

Incorrect: $\text{J/s} \neq \text{N m}$ (correct is $\text{J} = \text{N m}$)

▷ $e^{-8} \text{ J}$

▷ $\frac{15 \text{ J}}{5 \text{ kg/s}^2} = 3 \text{ m}^2$

▷ $\sqrt{25} \text{ K} = 5$

Incorrect: both sides of an equation must have the same dimension; here the left side has dimension $\text{length}^{1/2}$, right side is dimensionless

▷ $(e^7)^s$

Incorrect: cannot raise to a dimensional power

▷ $\tan\left(\frac{10 \text{ m}}{5 \text{ m}}\right)$

▷ $\sqrt{300 \text{ K}}$

▷ $\sin(t/\text{s})$, where t has dimension of time

▷ $\frac{3}{\text{s}}$

▷ $\sin(10 \text{ s})$

Incorrect: trigonometric function must have a dimensionless argument

Time and space 2



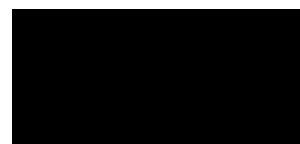
Volume contents, fluxes, supplies 3



Physical laws 4



The Seven Wonders of the world 5



Conservation & balances of matter 6



Conservation of electric charge 7



Conservation of magnetic flux 8



Balance of momentum 9



Balance of energy 10 

Balance of angular momentum 11



Remarks on momentum and energy 12 

Balance of entropy 13



Constitutive relations 14

