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Abstract

This document serves as both a template and demonstration of a comprehensive LaTeX system for scientific and technical writing. It implements a consistent visual notation system that distinguishes scalars, vectors, matrices, and tensors through distinct typographic styles. The template includes colored theorem boxes, glossary support, bibliography management, SI units integration, and enhanced mathematical commands. Five demonstration chapters illustrate all features through practical examples from mathematics, physics, and engineering. This template is production-ready and can be customized for research papers, technical reports, theses, or educational materials.

Contents

1 Notation System

This template uses a consistent visual notation system to distinguish between different mathematical objects.

1.1 Basic Notation

1.1.1 Scalars

Scalars are rendered in italic (default math mode):

$$x = 5, \quad t = 10, \quad \alpha = 0.5$$

1.1.2 Vectors

Vectors use bold with underline for clear distinction:

$$\underline{\mathbf{v}} = \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}, \quad \underline{\mathbf{F}} = m\underline{\mathbf{a}}$$

Position vector example:

$$\underline{\mathbf{r}} = x\underline{\hat{\mathbf{x}}} + y\underline{\hat{\mathbf{y}}} + z\underline{\hat{\mathbf{z}}}$$

1.1.3 Matrices

Matrices use bold with double underline:

$$\underline{\underline{\mathbf{A}}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

Matrix-vector multiplication:

$$\underline{\underline{\mathbf{A}}}\underline{\mathbf{x}} = \underline{\mathbf{b}}$$

1.1.4 Tensors

Higher-order tensors use bold calligraphic notation:

$$\boldsymbol{\mathcal{T}} = \sum_{i,j,k} T_{ijk}\, \underline{\mathbf{e}}_i \otimes \underline{\mathbf{e}}_j \otimes \underline{\mathbf{e}}_k$$

Stress tensor in continuum mechanics:

$$\boldsymbol{\sigma} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{bmatrix}$$

1.2 Unit Vectors

The template provides unit vectors for common coordinate systems:

Cartesian coordinates:

$$\underline{\mathbf{v}} = v_x\underline{\hat{\mathbf{x}}} + v_y\underline{\hat{\mathbf{y}}} + v_z\underline{\hat{\mathbf{z}}}$$

Cylindrical coordinates:

$$\underline{\mathbf{E}} = E_\rho\underline{\hat{\rho}} + E_\phi\underline{\hat{\phi}} + E_z\underline{\hat{\mathbf{z}}}$$

Spherical coordinates:

$$\underline{\mathbf{F}} = F_R \underline{\hat{\mathbf{R}}} + F_\theta \underline{\hat{\theta}} + F_\phi \underline{\hat{\phi}}$$

1.3 Why This Notation?

This notation system provides:

- **Visual clarity** – Each object type has distinct appearance
- **Reduced ambiguity** – No confusion between A (scalar) and $\underline{\underline{\mathbf{A}}}$ (matrix)
- **Better readability** – Complex equations are easier to parse
- **Consistency** – Throughout your entire document

2 Enhanced Math Commands

The template includes many mathematical shortcuts for common operations.

2.1 Derivatives

2.1.1 Partial Derivatives

First-order partial derivative:

$$\frac{\partial f}{\partial x} = \frac{\partial f}{\partial x}$$

Second-order partial derivative:

$$\frac{\partial^2 f}{\partial x^2} = \frac{\partial^2 f}{\partial x^2}$$

Mixed partial derivative:

$$\frac{\partial^2 f}{\partial x \partial y} = \frac{\partial^2 f}{\partial x \partial y}$$

Partial time derivative (common in physics):

$$\frac{\partial u}{\partial t} = \frac{\partial u}{\partial t}$$

2.1.2 Total Derivatives

First derivative:

$$\frac{\mathrm{d}s}{\mathrm{d}t} = \frac{ds}{dt}$$

Second derivative:

$$\frac{\mathrm{d}^2 x}{\mathrm{d}^2 t} = \frac{d^2 x}{dt^2} = \ddot{x}$$

2.2 Vector Calculus Operators

2.2.1 Gradient

$$\operatorname{grad} f = \nabla f = \frac{\partial f}{\partial x}\underline{\hat{\mathbf{x}}} + \frac{\partial f}{\partial y}\underline{\hat{\mathbf{y}}} + \frac{\partial f}{\partial z}\underline{\hat{\mathbf{z}}}$$

Example with electric potential:

$$\underline{\mathbf{E}} = -\operatorname{grad} V$$

2.2.2 Divergence

$$\operatorname{div} \underline{\mathbf{F}} = \nabla \cdot \underline{\mathbf{F}} = \frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z}$$

Gauss's law:

$$\operatorname{div} \underline{\mathbf{E}} = \frac{\rho}{\epsilon_0}$$

2.2.3 Curl

$$\operatorname{curl} \underline{\mathbf{F}} = \nabla \times \underline{\mathbf{F}}$$

Faraday's law:

$$\operatorname{curl} \underline{\mathbf{E}} = -\frac{\partial \underline{\mathbf{B}}}{\partial t}$$

2.3 Vector Operations

2.3.1 Dot Product

$$\underline{\mathbf{a}} \bullet \underline{\mathbf{b}} = |\underline{\mathbf{a}}||\underline{\mathbf{b}}| \cos\theta$$

2.3.2 Vector Projection

Projection of $\underline{\mathbf{b}}$ onto $\underline{\mathbf{a}}$:

$$\operatorname{proj}_{\underline{\mathbf{a}}} \underline{\mathbf{b}} = \operatorname{proj}_{\underline{\mathbf{a}}} \underline{\mathbf{b}} = \frac{\underline{\mathbf{a}} \bullet \underline{\mathbf{b}}}{|\underline{\mathbf{a}}|^2} \underline{\mathbf{a}}$$

2.3.3 Angle Between Vectors

$$\theta = \angle(\underline{\mathbf{a}}, \underline{\mathbf{b}}) = \arccos\left(\frac{\underline{\mathbf{a}} \bullet \underline{\mathbf{b}}}{|\underline{\mathbf{a}}||\underline{\mathbf{b}}|}\right)$$

2.4 Matrix Operations

2.4.1 Trace

$$\operatorname{tr}(\underline{\underline{\mathbf{A}}}) = \sum_{i=1}^{n} A_{ii}$$

2.4.2 Rank

$$\operatorname{rank}(\underline{\underline{\mathbf{A}}}) = \text{number of linearly independent columns}$$

2.5 Utilities

2.5.1 Absolute Value and Norm

$$|x| = |x|, \quad \|\underline{\mathbf{v}}\| = \sqrt{\underline{\mathbf{v}} \bullet \underline{\mathbf{v}}}$$

2.5.2 Probability

$$\mathrm{P}\left(A \cap B\right) = \mathrm{P}\left(A\right) \cdot \mathrm{P}\left(B|A\right)$$

2.5.3 Defined As

$$f(x) \stackrel{\text{def}}{=} x^2 + 2x + 1$$

2.6 Constants

The template provides common constants:

$$\mathrm{e} = 2.71828\ldots \quad \text{(Euler's number)}$$
$$\mathrm{j} = \sqrt{-1} \quad \text{(imaginary unit)}$$
$$\mathrm{d} \quad \text{(differential, e.g., } \int f(x)\mathrm{d}x\text{)}$$

Example with Euler's formula:

$$\mathrm{e}^{\mathrm{j}\theta} = \cos\theta + \mathrm{j}\sin\theta$$

3 Theorem Boxes

The template provides beautiful colored boxes for theorems, definitions, and notes.

3.1 Numbered Theorem Environments

3.1.1 Theorems

Theorem 3.1: Pythagorean Theorem

In a right triangle with legs of length a and b, and hypotenuse of length c:

$$a^2 + b^2 = c^2$$

Reference it later: See Theorem 3.1.

Theorem 3.2: Fundamental Theorem of Calculus

If f is continuous on $[a, b]$ and F is an antiderivative of f, then:

$$\int_a^b f(x)\mathrm{d}x = F(b) - F(a)$$

3.1.2 Lemmas and Corollaries

Lemma 3.3: Cauchy-Schwarz Inequality

For any vectors $\underline{\mathbf{u}}$ and $\underline{\mathbf{v}}$:

$$|\underline{\mathbf{u}} \bullet \underline{\mathbf{v}}| \leq \|\underline{\mathbf{u}}\| \cdot \|\underline{\mathbf{v}}\|$$

Corollary 3.4: Triangle Inequality

For any vectors $\underline{\mathbf{u}}$ and $\underline{\mathbf{v}}$:

$$\|\underline{\mathbf{u}} + \underline{\mathbf{v}}\| \leq \|\underline{\mathbf{u}}\| + \|\underline{\mathbf{v}}\|$$

3.1.3 Definitions

Definition 3.1. Linear Independencelinindep A set of vectors $\{\underline{\mathbf{v}}_1, \underline{\mathbf{v}}_2, \ldots, \underline{\mathbf{v}}_n\}$ is **linearly independent** if:

$$c_1\underline{\mathbf{v}}_1 + c_2\underline{\mathbf{v}}_2 + \cdots + c_n\underline{\mathbf{v}}_n = \underline{\mathbf{0}}$$

implies $c_1 = c_2 = \cdots = c_n = 0$.

Definition 3.2. Eigenvalue and Eigenvectoreigen A scalar λ is an **eigenvalue** of matrix $\underline{\underline{\mathbf{A}}}$ if there exists a non-zero vector $\underline{\mathbf{v}}$ (the **eigenvector**) such that:

$$\underline{\underline{\mathbf{A}}}\underline{\mathbf{v}} = \lambda\underline{\mathbf{v}}$$

3.1.4 Notes

Note 3.5: Important Observation

The notation system helps distinguish between $\underline{\underline{\mathbf{A}}}\underline{\mathbf{v}}$ (matrix times vector) and $A\underline{\mathbf{v}}$ (scalar times vector) at a glance.

3.2 Plain Theorem Environments

For backward compatibility, plain (non-colored) environments are also available:

Example 3.3 (Finding Eigenvalues)**.** For the matrix $\underline{\underline{\mathbf{A}}} = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$, solve:

$$\det(\underline{\underline{\mathbf{A}}} - \lambda\underline{\underline{\mathbf{I}}}) = 0$$

$$\det \begin{bmatrix} 2-\lambda & 1 \\ 1 & 2-\lambda \end{bmatrix} = (2-\lambda)^2 - 1 = 0$$

Therefore $\lambda = 3$ or $\lambda = 1$.

Remark 3.4 (On Numerical Stability)**.** When computing eigenvalues numerically, use specialized algorithms like QR decomposition rather than direct determinant computation.

3.3 Utility Boxes

3.3.1 Warning Box

Division by zero is undefined! Always check denominators before computing.

3.3.2 Important Box

Remember: matrix multiplication is NOT commutative!

$$\underline{\underline{\mathbf{AB}}} \neq \underline{\underline{\mathbf{BA}}} \quad \text{(in general)}$$

3.3.3 Tip Box

Tip 3.1: Computational Efficiency

For large sparse matrices, use specialized sparse solvers instead of dense matrix operations to save memory and computation time.

3.3.4 Solution Box

Solution

Solution to Example:

1. Set up the characteristic equation
2. Solve for eigenvalues: $\lambda_1 = 3$, $\lambda_2 = 1$
3. Find eigenvectors by solving $(\underline{\underline{\mathbf{A}}} - \lambda\underline{\underline{\mathbf{I}}})\underline{\mathbf{v}} = \underline{\mathbf{0}}$

3.3.5 Answer Box

Final Answer: $\lambda_1 = 3$, $\lambda_2 = 1$

4 Advanced Features

4.1 Glossary and Acronyms

The template supports glossaries and acronyms using the `glossaries` package.

4.1.1 Using Glossary Terms

First mention of a term shows the full description: wavelength.
Subsequent mentions show just the term: wavelength.
You can also use: Frequency (capitalized), wavelengths (plural).

4.1.2 Using Acronyms

First use shows full form: Electromagnetic (EM).
Later uses show abbreviation: EM.
Force full form: Electromagnetic (EM).

4.1.3 Adding Glossary Entries

Edit `config/glossary.tex` to add your terms:

```
\newglossaryentry{myterm}{
  name=my term,
  description={Description of my term}
}

\newacronym{api}{API}{Application Programming Interface}
```

4.2 Bibliography and Citations

The template is ready for BibTeX citations. Add entries to `references.bib`:

```
@article{shannon1948,
  author = {Shannon, Claude E.},
  title = {A Mathematical Theory of Communication},
  journal = {Bell System Technical Journal},
```

```
  year = {1948}
}
```

Then cite in your document: As shown by Shannon [?], information has entropy.

To compile with bibliography:

```
pdflatex main
bibtex main
pdflatex main
pdflatex main
```

4.3 SI Units with siunitx

The `siunitx` package provides consistent unit formatting:

4.3.1 Basic Units

- Speed of light: $3 \times 10^8\,\mathrm{m\,s^{-1}}$
- Temperature: $273.15\,\mathrm{K}$
- Frequency: $2.4\,\mathrm{GHz}$
- Energy: $13.6\,\mathrm{eV}$

4.3.2 Ranges

Wavelength range: $400\,\mathrm{nm}$ to $700\,\mathrm{nm}$

Temperature range: $0\,^{\circ}\mathrm{C}$ to $100\,^{\circ}\mathrm{C}$

4.3.3 In Equations

The wavelength-frequency relationship:

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8\,\mathrm{m\,s^{-1}}}{2.4 \times 10^9\,\mathrm{Hz}} = 12.5\,\mathrm{cm}$$

4.4 Quantum Mechanics Notation

4.4.1 Bra-Ket Notation

Ket vector (state):

$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

Bra vector (dual):

$$\langle\psi| = \alpha^*\,\langle 0| + \beta^*\,\langle 1|$$

Inner product:

$$\langle\phi|\psi\rangle = \int_{-\infty}^{\infty} \phi^*(x)\psi(x)\mathrm{d}x$$

4.4.2 Operators

Hamiltonian operator:

$$\hat{H}\left|\psi\right\rangle = E\left|\psi\right\rangle$$

Commutator:

$$\left[\hat{\hat{x}}, \hat{\hat{p}}\right] = \mathrm{j}\hbar$$

Position and momentum operators:

$$\hat{x}\left|x\right\rangle = x\left|x\right\rangle, \quad \hat{p} = -\mathrm{j}\hbar\frac{\partial}{\partial x}$$

4.4.3 Expectation Values

$$\langle\hat{A}\rangle = \left\langle\psi\middle|\hat{A}\psi\right\rangle = \int \psi^*(x)\hat{A}\psi(x)\mathrm{d}x$$

4.5 Custom Lists with enumitem

4.5.1 Customized Itemize

- First item
- Second item
- Third item

4.5.2 Customized Enumerate

(a) Step one

(b) Step two

(c) Step three

4.6 Tables with booktabs

The template includes the `booktabs` package for professional tables:

Table 1: Comparison of notation styles

Object	Standard	This Template
Scalar	x	x
Vector	$\mathbf{v}$ or $\vec{v}$	$\underline{\mathbf{v}}$
Matrix	$\mathbf{A}$	$\underline{\underline{\mathbf{A}}}$
Tensor	$\mathcal{T}$	$\underline{\underline{\underline{\mathcal{T}}}}$

5 Complete Example: Electromagnetic Wave

This example demonstrates multiple features of the template in a realistic context.

5.1 Problem Statement

Calculate the electric and magnetic fields of a plane electromagnetic wave propagating in free space.

5.2 Theory

Definition 5.1. Electromagnetic Waveemwave An EM wave is a solution to Maxwell's equations in vacuum that satisfies:

$$\nabla^2 \underline{\mathbf{E}} = \mu_0 \epsilon_0 \frac{\partial^2 \underline{\mathbf{E}}}{\partial t^2}, \quad \nabla^2 \underline{\mathbf{B}} = \mu_0 \epsilon_0 \frac{\partial^2 \underline{\mathbf{B}}}{\partial t^2}$$

Theorem 5.1: Wave Equation Solution

A plane wave solution has the form:

$$\underline{\mathbf{E}}(\underline{\mathbf{r}}, t) = \underline{\mathbf{E}}_0 \cos(\underline{\mathbf{k}} \bullet \underline{\mathbf{r}} - \omega t) \tag{1}$$

$$\underline{\mathbf{B}}(\underline{\mathbf{r}}, t) = \underline{\mathbf{B}}_0 \cos(\underline{\mathbf{k}} \bullet \underline{\mathbf{r}} - \omega t) \tag{2}$$

where $\omega = c|\underline{\mathbf{k}}|$ and $c = 3 \times 10^8\,\mathrm{m\,s^{-1}}$.

5.3 Key Relationships

5.3.1 Dispersion Relation

The wavelength and frequency are related by:

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega}$$

For a wave at $f = 2.4\,\mathrm{GHz}$:

$$\lambda = \frac{3 \times 10^8\,\mathrm{m\,s^{-1}}}{2.4 \times 10^9\,\mathrm{Hz}} = 12.5\,\mathrm{cm}$$

5.3.2 Field Relationships

Theorem 5.2: Perpendicularity Conditions

The electric field, magnetic field, and wave vector satisfy:

$$\underline{\mathbf{E}} \perp \underline{\mathbf{B}}, \quad \underline{\mathbf{E}} \perp \underline{\mathbf{k}}, \quad \underline{\mathbf{B}} \perp \underline{\mathbf{k}} \tag{3}$$

Magnitude relationship:

$$|\underline{\mathbf{B}}| = \frac{|\underline{\mathbf{E}}|}{c}$$

5.4 Specific Example

Example 5.2 (Plane Wave Propagating in +z Direction)**.** Consider a wave with $\underline{\mathbf{k}} = k\underline{\hat{\mathbf{z}}}$ where $k = 5.03 \times 10^8\,\mathrm{m^{-1}}$.

The electric field polarized in $\underline{\hat{\mathbf{x}}}$ direction:

$$\underline{\mathbf{E}}(z, t) = E_0 \cos(kz - \omega t)\underline{\hat{\mathbf{x}}}$$

The corresponding magnetic field (from $\underline{\mathbf{B}} = \frac{1}{c}\hat{k} \times \underline{\mathbf{E}}$):

$$\underline{\mathbf{B}}(z, t) = \frac{E_0}{c} \cos(kz - \omega t)\underline{\hat{\mathbf{y}}}$$

where:

- $E_0 = 1\,\mathrm{V\,m^{-1}}$ (amplitude)
- $\omega = kc = 1.51 \times 10^{17}\,\mathrm{rad\,s^{-1}}$
- $f = \omega/(2\pi) = 2.4\,\mathrm{GHz}$

5.5 Energy and Momentum

5.5.1 Energy Density

The electromagnetic energy density:

$$u = \frac{1}{2}\left(\epsilon_0|\underline{\mathbf{E}}|^2 + \frac{1}{\mu_0}|\underline{\mathbf{B}}|^2\right)$$

Note 5.3: Equal Contributions

For plane waves, the electric and magnetic contributions are equal:

$$u_E = \frac{1}{2}\epsilon_0|\underline{\mathbf{E}}|^2 = u_B = \frac{1}{2\mu_0}|\underline{\mathbf{B}}|^2$$

5.5.2 Poynting Vector

Energy flux (power per area):

$$\underline{\mathbf{S}} = \frac{1}{\mu_0}\underline{\mathbf{E}} \times \underline{\mathbf{B}}$$

For our example:

$$|\underline{\mathbf{S}}| = \frac{E_0^2}{c\mu_0}\cos^2(kz - \omega t)$$

Time-averaged intensity:

$$\langle S\rangle = \frac{E_0^2}{2c\mu_0} = \frac{(1\,\mathrm{V\,m^{-1}})^2}{2 \times 3 \times 10^8\,\mathrm{m\,s^{-1}} \times 1.257 \times 10^{-6}\,\mathrm{H\,m^{-1}}}$$

5.6 Solution Summary

Solution

For a 2.4 GHz plane wave with $E_0 = 1\,\mathrm{V\,m^{-1}}$:

1. **Wavelength:** $\lambda = 12.5\,\mathrm{cm}$
2. **Wave vector:** $k = 5.03 \times 10^8\,\mathrm{m^{-1}}$
3. **Electric field:** $\underline{\mathbf{E}} = E_0\cos(kz - \omega t)\underline{\hat{\mathbf{x}}}$
4. **Magnetic field:** $\underline{\mathbf{B}} = (E_0/c)\cos(kz - \omega t)\underline{\hat{\mathbf{y}}}$
5. **Power density:** $\langle S\rangle \approx 1.3\,\mathrm{mW\,m^{-2}}$

5.7 Key Takeaways

Tip 5.1: Using the Notation System

Notice how the notation system helps:

- $\underline{\mathbf{E}}, \underline{\mathbf{B}}, \underline{\mathbf{k}}, \underline{\mathbf{S}}$ are clearly vectors (bold + underline)
- E_0, k, ω, c are clearly scalars (italic)
- No confusion in complex equations with many variables

Always verify that $\underline{\mathbf{E}} \perp \underline{\mathbf{B}} \perp \underline{\mathbf{k}}$ for plane waves. If these relationships don't hold, you may have made an error!