



A SunCam Online Continuing Education Course

**Alabama Engineering Ethics +  
Background / Legality / Code Comparison**  
by  
**John A Camara, BS, MS, PE, TF**



A SunCam Online Continuing Education Course

**Nomenclature<sup>1</sup>**

ABET	Accreditation Board for Engineering and Technology	-
IEEE	Institute of Electrical & Electronics Engineers	-
NCEES	National Council of Examiners for Engineering and Surveying	-
NSPE	National Society of Professional Engineers	-
NASA	National Aeronautics and Space Administration	-

**Tables**

TABLE 1: COMPARISON OF CODES .....13

---

<sup>1</sup> Not all the nomenclature, symbols, or subscripts may be used in this course—but they are related and may be found when reviewing the references listed for further information. Further, all the nomenclature, symbols, or subscripts will be found in of many electrical courses (on SunCam, PDH Academy, and also in many texts). For guidance on nomenclature, symbols, and electrical graphics: IEEE 280-2021, IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering, New York: IEEE; and IEEE 315-1975, Graphic Symbols for Electrical and Electronics Diagrams, New York: IEEE, approved 1975, reaffirmed 1993.



A SunCam Online Continuing Education Course



A SunCam Online Continuing Education Course

TABLE OF CONTENTS

**Nomenclature .....2**

**Tables .....2**

**COURSE REFERENCES..... 5**

**BACKGROUND..... 5**

**Terminology .....5**

**Key Differences and Relationship.....6**

**Reason for Codes of Ethics .....6**

**Purpose of a Code of Ethics .....6**

**Ethical Priorities.....7**

    Client and Employers.....7

    Suppliers .....8

    Engineers.....8

    Public.....8

**Competitive Bidding.....9**

**ALABAMA CODE OF ETHICS ..... 9**

**Legal Terminology & Sources of Information.....9**

**Alabama Code of Ethics Statutory Authority .....9**

**Code of Ethics (Canon V) .....10**

**CODE COMPARISON ..... 13**

**REFERENCES ..... 14**

**Appendix A: Equivalent Units Of Derived And Common SI Units .....15**

**Appendix B: Physical Constants .....16**

**Appendix C: Fundamental Constants .....18**

**Appendix D: Mathematical Constants, Signs/Symbols, Maxwell’s Equations.....19**

**Appendix E: The Greek Alphabet .....20**

**Appendix F: SI Prefixes .....20**

**Appendix G: Comparison of Electric & Magnetic Equations .....21**

**Appendix H: Coordinate Systems and Related Operations.....23**



## A SunCam Online Continuing Education Course

### COURSE REFERENCES

The theoretical information is primarily from one of the author's books, Ref. [A]. The NEC Ref. [B] is always a useful source for electrical engineers. Information useful in many aspects of electric engineering may be found in [C] and [D]. Reference [E] has detailed descriptions of analysis techniques. Reference [F] covers many terms in EE with excellent definitions and explanations. Reference [G] provides excellent electric power engineering background. Reference [H] and beyond are the focus of this course. The appendices (A-F) cover information useful in many engineering tasks. Appendix (G) provides a side by side comparison of electric and magnetic equations. Appendix (H) provides useful information on coordinate systems and related operations. Use these texts or their counterparts for indepth information. References in bold are highly recommended. The latest editions are recommended.

This course will focus on basics, that rarely change, that provide the basis for all other knowledge.

### BACKGROUND

#### Terminology

For a company, especially a large one, though it may not be code, they often layout their values using the following terminology in an attempt to answer "why", "how", and "what" to provided individuals in an organization with direction, guiding behavior, and anchoring core values.

- Purpose (Why)
- Mission Statement (How)
- Creed (What/Beliefs/Core Values)

Larger companies may expand this list; though this is still focused Why/How/What.

- Purpose
- Mission
- Core Values
- Vision (Goal/Focus)
- Strategic Goals (Long Term Goals)

An example from The Boeing Company follows.

- **Purpose:** The company aims to innovate to advance global aerospace, defense, and space capabilities.
- **Mission:** Protect, connect, explore, and inspire the world through aerospace innovation.



## A SunCam Online Continuing Education Course

- **Core Values & Focus:** Safety is the foundation of all operations, alongside a dedication to quality, integrity, and sustainability.
- **Vision:** To be the "Best in Aerospace and Enduring Global Industrial Champion".
- **Strategic Goals:** Transforming to a stronger company through a focus on environmental, social, and corporate governance (ESG) goals, including reaching net-zero emissions by 2050.

### *Key Differences and Relationship*

- **Mission vs. Creed:** While a mission statement defines *behavioral intent* (what you do), a creed focuses on *belief* (what you believe).
- **Purpose vs. Mission:** Purpose is the reason, while mission is the action taken to fulfill that purpose.
- **Usage:** They work together to create a cohesive strategy for personal or organizational success.

Sometimes a *creed* is accomplished by taking a *pledge*, as does the National Society of Professional Engineers and the Engineering Honor Society, Tau Beta Pi. A *cannon* is a fundamental belief. A *rule* is a guiding principle, standard, or norm. All these represents *codes*, which is a system of non-statutory, non-mandatory cannons of conduct.

*If such codes are passed by a legislative branch of government, they then become statutes to which one is legally bound.*

### **Reason for Codes of Ethics**

The fundamental reason for a code of ethics is that individuals cannot be counted on in all instances to act in a “proper” or “moral” manner. Therefore, the various codes are attempts to define what is proper or moral for both a company, a society of individuals [PE’s], or even a country.

### **Purpose of a Code of Ethics**

Many different codes of ethics have been created by engineering societies, registration boards and other organizations: IEEE, ABET, NCEES, et cetera. Their overriding purpose is to guide the conduct and decision making of engineers. Most are educational in nature though they have been used for disciplinary actions, or in the case of statutes, legal action.

The theme of the codes tends to be that an engineer is to faithful, honest, and professional service to the employer and client, while at the same time protecting public health, safety, and welfare.



## A SunCam Online Continuing Education Course

There is a distinction between what is legal and what is ethical. As a single example, an engineer may be allowed by contract to assign his responsibilities to other parties; but, it would be unethical to do so without informing the client.

### **Ethical Priorities**

Any engineering job will involve conflicts and trade-offs. Nevertheless, an engineer dealing with others should consider the following, in order from highest to lowest priority:

- society and the public
- the law
- the engineering profession
- the engineer's client
- the engineer's firm
- other involved engineers
- the engineer personally

### *CLIENT AND EMPLOYERS*

The most common guidance in ethical codes regarding clients follow.

- Don't accept task one is not qualified to perform. [Most states license the "Professional Engineer" without stating the area of expertise.]
- The client's interest must be protected. [This nominally extends beyond the legal contract.]
- The engineer is not bound by a client's interests where they would not be successful, dishonest, or unethical. [One must be able to say "No". Still a professional explanation is warranted.]
- Avoid conflicts of interest. [Include those detrimental to the client, the profession, or the engineer.]
- Recognized one's limitations and utilize peers when necessary.
- Freely admit any errors made. [And, correct them goes without saying.]

Of note, all courts of law require engineers to perform their duties in a many consistent with normal professional standards. This does not mean error free. If the engineer perform the necessary duties, has them checked by a competent engineer, and an engineering error is found, the engineer is likely found *responsible, but not negligent*.



## A SunCam Online Continuing Education Course

### *SUPPLIERS*

Manufacturers, contractors, and vendors [suppliers]. The most common ethical guidance follows.

- Interpret contract documents fairly, and enforce the plans and specification within.
- Plans and specifications must be complete, definitive, and specific.
- Suppliers should not be required to spend time or money for items not in the specifications or contracts.
- Do not unduly delay suppliers.
- Do not accept, or solicit, gifts from suppliers.

### *ENGINEERS*

Engineers working together should protect the engineering professional as a whole. The most common ethical guidance follows.

- An engineer should not attempt to maliciously injure the professional reputation, business practice, or employment of another engineer.
- Inform another engineer if the work is being reviewed.
- Subject to legal and proprietary constraints, an engineer should report, publish, and distribute information of use to other engineers.

### *PUBLIC*

The primary driver is for the engineer to place service to mankind over personal gain. The most common ethical guidance follows.

- Consider the safety and welfare of the public in all work performed.
- Uphold the honor and dignity of the engineering profession throughout the work, and by expressing opinions only in areas of knowledge.
- Maintain skills at state-of-the-art level.<sup>2</sup>
- Notify proper authorities when decisions adversely affect public safety or welfare.<sup>3</sup>

---

<sup>2</sup> Hence, this course and your efforts in this regard.

<sup>3</sup> This is now known as *whistle blowing*.



## A SunCam Online Continuing Education Course

### Competitive Bidding

Competitive bidding went to the US Supreme court in 1971 in a case involving the NSPE. In it, the constraint against competitive bidding in the societies ethical code was struck down as being against the Sherman Antitrust Act (unreasonable constraint on trade). The Supreme Court does not require competitive it forbade a prohibition of it in ethical codes.

Consider the following points and guidelines.

- Individual engineers and companies can refuse to bid.
- *Statutes* that prohibit competitive bidding are unaffected.

## ALABAMA CODE OF ETHICS

### Legal Terminology & Sources of Information

The *U.S. Code* only contains public laws that are permanent and general in nature. Laws that are temporary, private (affecting specific individuals/entities), or act as appropriations (budgetary) are generally excluded or just noted, as they do not apply permanently to the entire nation.

Key details regarding *U.S. laws and the Code* follow. The *Official Source* is the actual law is found in the *Statutes at Large*, which is the chronological, authorized publication of *all acts passed by Congress*, while the *U.S. Code* is an organized, thematic re-arrangement. The Office of the Law Revision Counsel (OLRC) reviews new laws to determine if they are permanent and general, at which point they are classified and integrated into the Code.<sup>4,5</sup>

The *U.S. Code* does not include federal agency regulations, which are found in the *Code of Federal Regulations* (CFR), nor does it include court decisions, treaties, or state/local laws.

Legally then, one follows first Federal Law in the Statutes at Large, then the U.S. Code, then the CFR, then State Law, and finally, the individual Company Policy.

In Alabama, the Engineering Ethics is Law.

### Alabama Code of Ethics Statutory Authority

---

<sup>4</sup> What Gets Excluded from the US Code: Private laws, temporary measures (like one-year spending bills), and laws specific to a small group or place are not codified.

<sup>5</sup> Exceptions: Some titles of the U.S. Code have been enacted into "positive law," making them the *official legal evidence*, while others are "prima facie" (on its face) evidence, meaning the Statutes at Large controls if there is a discrepancy.



## A SunCam Online Continuing Education Course

Statutory Authority for PE Board [and thus the Ethics Canon] comes from Ala. Code § 34-11-35 (1975). It is maintained in Alabama Administrative Code 330-X-14. Ethics is in Canon V.

### **Code of Ethics (Canon V)**

The engineer or land surveyor shall contribute to the maintenance, integrity, independence and competency of the engineering or land surveying profession as follows:

(a) The engineer or land surveyor shall not:

1. Violate any provision of the Alabama law regulating the practice of engineering and land surveying or of the Administrative Code of the Board of Licensure for Professional Engineers and Land Surveyors;
2. Participate, directly or indirectly, in any plan, scheme or arrangement attempting or having as its purpose the evasion of any provision of the Alabama law regulating the practice of engineering and land surveying;
3. Fail to exercise reasonable care or diligence to prevent his or her partners, associates, and employees from engaging in conduct which if done by him or her, would violate any provision of the Alabama Law regulating the practice of engineering and land surveying;
4. Engage in any illegal conduct, whether a felony or misdemeanor, the essential element of which is dishonesty;
5. Engage in any conduct that discredits or tends to discredit the profession of engineering or land surveying;
6. Permit or allow, his or her professional identification, seal, firm, or business name, or his or her services to be used or made use of, directly or indirectly, or in any manner whatsoever, so as to make possible or create the opportunity for the unauthorized practice of engineering or land surveying by any person, firm or corporation in this state;
7. Perform any acts, allow omissions or make any assertions or representations which are fraudulent, deceitful, or misleading, or which in any manner whatsoever tend to create a misleading impression;



A SunCam Online Continuing Education Course

8. Knowingly associate with or permit or allow the use of his or her name, firm name or professional identification or seal in any business venture, project or enterprise which he or she knows or has reason to believe is engaged in professional practices which violate any provision of the Alabama Law regulating the practice of engineering and land surveying;

9. Knowingly associate with or permit the use of his or her name, professional identification, seal, firm or business name in connection with any venture or enterprise which he or she knows, or has reason to believe, is engaging in trade, business or professional practice of a fraudulent, deceitful or dishonest nature;

10. Injure or attempt to injure or damage the professional reputation of another by any means whatsoever; provided and except, however, that this shall not relieve an engineer or land surveyor of the obligation to expose unethical or illegal conduct to the proper authorities or preclude a frank but private appraisal of engineers or land surveyors or other persons or firms considered for employment;

11. Aid or abet, directly or indirectly, any unlicensed person in connection with the unauthorized practice of engineering or land surveying; or any firm or corporation in the practice of engineering or land surveying unless carried on in accordance with the provisions of Chapter 11, Title 34 of the Alabama Law regulating the practice of engineering and land surveying;

12. Place his or her seal, signature, date and license number on a document constituting a certification that the document was prepared by the licensee unless the document was prepared by the licensee or under his or her direct control and personal supervision or unless the licensee has reviewed the document in sufficient depth to fully coordinate and assume responsibility for plans prepared by another licensed professional engineer or licensed professional land surveyor.

13. Review the work of another engineer or land surveyor, for the same employer, except with the knowledge or consent of the engineer or land surveyor, unless the connection of the engineer or land surveyor with the work has been terminated.

14. Participate in procurement procedures for engineering or land surveying services either by providing the bids or in requesting bids from other professional engineers or land surveyors where bidding is the primary consideration except as allowed by state law.

15. Fail to respond to the Board within 60 days of receipt of Board inquiries.



A SunCam Online Continuing Education Course

- (b) The engineer or land surveyor shall be personally and professionally responsible and accountable for the care, custody, control and use of his or her engineer's or land surveyor's seal, professional signature, and identification. The engineer or land surveyor whose seal has been lost, misplaced or stolen shall, upon discovery of its loss, report the loss immediately to the Board, which may invalidate the license number of the seal, if it deems this necessary, and issue another license number to the engineer or land surveyor.
- (c) When in public service as a member or employee of any governmental body, agency or department, the engineer or land surveyor shall not participate, directly or indirectly, use or make use of any property, facility or service of such governmental body, agency or department for the benefit of any private business or activity in which such engineer or land surveyor also may be engaged, unless prior, proper authority is obtained in writing.
- (d) The engineer or land surveyor shall not, directly or indirectly, use or make use of any property, facility or service of his or her client or employer for the benefit of the engineer or land surveyor, unless prior, proper authority is obtained in writing.
- (e) The engineer or land surveyor shall not practice or offer to practice engineering or land surveying in any governmental jurisdiction in which to do so would be in violation of the laws regulating the practice of professional engineering or professional land surveying in that jurisdiction.
- (f) Licensees having knowledge of possible/probable violations of any of these Rules of Professional Conduct shall provide the Board with the information and cooperate as necessary to make the final determination of such violation.
- (g) It shall be the duty and sole responsibility of each licensee and intern to provide written notification to the Board of any changes to their mailing address and business affiliation within 30 days after the change.
- (h) The engineer or land surveyor must provide written notification to the Board within 30 days of a disciplinary action taken against them by other licensing boards.
- (i) The engineer or land surveyor must provide written notification to the Board within 30 days of a conviction, a plea of guilty, or nolo contendere to any felony crime, or misdemeanor directly related to the practice of engineering or land surveying.



## A SunCam Online Continuing Education Course

### CODE COMPARISON

Codes vary slightly. Not all have the force of law. NCEES has an excellent comparison available at the following website: <https://ncees.org/wp-content/uploads/U.S.-Codes-of-Ethics-handout-2019.pdf>. A snippet of which is shown in the table below.

**Table 1: Comparison of Codes**

**Summary of US Engineering Societies' Codes of Ethics**

Engineering Society	Structure	Public Health, Safety, and Welfare	Sustainability/Environment/Resilience	Disclosure of Concerns to Clients	Disclosure of Concerns to Authorities
AIAA - American Institute of Aeronautics and Astronautics	10 Canons, Guidelines to Practice [Last update: 2013]	1. Hold paramount the safety, health, and welfare of the public in the performance of their duties.		2c. Report to employers, clients, or government, as appropriate, any matters believed to represent a contravention of law, regulation, health, safety or ethical standards.	1c. Report suspected violations of this element of the code to the proper authority and cooperate in furnishing further information and assistance as required.
AIChE - American Institute of Chemical Engineers	Bulleated list of provisions [Last update: 2015]	1. Hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties.	1. Hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties.	2. Formally advise their employers or clients (and consider further disclosure, if warranted) if they perceive that a consequence of their duties will adversely affect the present or future health or safety of their colleagues or the public.	2. Formally advise their employers or clients (and consider further disclosure, if warranted) if they perceive that a consequence of their duties will adversely affect the present or future health or safety of their colleagues or the public.
ANS - American Nuclear Society	Fundamental Principle, 12 Practices [As adopted: 2003]	1. We hold paramount the safety, health, and welfare of the public and fellow workers...	1. ... work to protect the environment, and strive to comply with the principles of sustainable development in the performance of our professional duties	2. We will formally advise our employers, clients, or any appropriate authority and, if warranted, consider further disclosure, if and when we perceive that pursuit of our professional duties might have adverse consequences for the present or future public and fellow worker health and safety or the environment.	2. We will formally advise our employers, clients, or any appropriate authority and, if warranted, consider further disclosure, if and when we perceive that pursuit of our professional duties might have adverse consequences for the present or future public and fellow worker health and safety or the environment.
ASCE - American Society of Civil Engineers	Fundamental Principles, 8 Canons, Guidelines to Practice [Last updated: 2017]	1. Engineers shall hold paramount the safety, health and welfare of the public...	1. Engineers shall... strive to comply with the principles of sustainable development in the performance of their professional duties.	1c. Engineers whose professional judgment is overruled under circumstances where the safety, health and welfare of the public are endangered, or the principles of sustainable development ignored, shall inform their clients or employers of the possible consequences.	1c. Engineers who have knowledge or reason to believe that another person or firm may be in violation of any of the provisions of Canon 1 shall present such information to the proper authority in writing and shall cooperate with the proper authority in furnishing such further information or assistance as may be required.
ASME - American Society of Mechanical Engineers	Fundamental Principles, 10 Canons, Criteria for Interpretation [Last update: 1999]	1. Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.	1. Engineers shall consider environmental impact and sustainable development in the performance of their professional duties. 8a. Engineers shall concern themselves with the impact of their plans and designs on the environment. 8b. Engineers shall consider development that meets the needs of the present without compromising the ability of future generations to meet their own needs.	1c. Whenever the Engineer's professional judgments are over-ruled under circumstances where the safety, health, and welfare of the public are endangered, the Engineers shall inform their clients and/or employers of the possible consequences.	1c. If engineers have knowledge or reason to believe that another person or firm may be in violation of any of the provisions of these Canons, they shall present such information to the proper authority in writing and shall cooperate with the proper authority in furnishing such further information or assistance as may be required. 8a. ...concern themselves with the impact of their plans and designs on the environment. When the impact is a clear threat to health or safety of the public, then the guidelines for this Canon revert to those of Canon 1. 8b. When the impact of the trade-off between economic, ecological, and social issues forms a clear threat to health or safety of the public, then the guidelines for this Canon revert to those of Canon 1.
IEEE - Institute of Electrical and Electronics Engineers	10 Canons [Last update: 2017]	1 to hold paramount the safety, health, and welfare of the public; to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment.	1. ... to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;	1. ... to disclose promptly factors that might endanger the public or the environment	1. ... to disclose promptly factors that might endanger the public or the environment
ISA - International Society of Automation	Preamble, 12 Articles [Originally Adopted: 1986]	1. ... hold paramount the safety, health and welfare of the public in the performance of their duties, and shall notify our employer or client and such other authority as may be appropriate where such obligations are abused.		1. ... hold paramount the safety, health and welfare of the public in the performance of their duties, and shall notify our employer or client and such other authority as may be appropriate where such obligations are abused.	1. ... hold paramount the safety, health and welfare of the public in the performance of their duties, and shall notify our employer or client and such other authority as may be appropriate where such obligations are abused.
ITE - Institute of Transportation Engineers	Preamble, 22 Canons [Last update: 2017]	1. The member will have due regard for the safety, health and welfare of the public in the performance of professional duties. 13. The member will guard against conditions that are dangerous or threatening to life, limb, or property on work for which the member is responsible, or, if not responsible, will promptly call such conditions to the attention of those who are responsible.	3. The member will strive to improve the public's quality of life through an economically, socially and environmentally sound transportation system that supports a sustainable society. 4. The member will consider the need for resilience in the design and operations of the transportation system, as a means of enhancing society's ability to respond and recover from economic, technological, or physical interruption of varying durations.	12. The member will indicate to employer or client the adverse consequences to be expected by overriding professional judgment. 13. The member will guard against conditions that are dangerous or threatening to life, limb, or property on work for which the member is responsible, or, if not responsible, will promptly call such conditions to the attention of those who are responsible.	13. The member will guard against conditions that are dangerous or threatening to life, limb, or property on work for which the member is responsible, or, if not responsible, will promptly call such conditions to the attention of those who are responsible.
NCEES - National Council of Examiners for Engineering and Surveying (model rules)	3 Subheadings, Canons under Each [Originally Adopted: 1990]	A.1. Licensees shall be cognizant that their first and foremost responsibility is to the health, safety, and welfare of the public when performing services for clients and employers.		A.3. Licensees shall notify their employer or client and such other authority as may be appropriate when their professional judgment is overruled when the health, safety, or welfare of the public is endangered.	A3. Licensees shall notify their employer or client and such other authority as may be appropriate when their professional judgment is overruled when the health, safety, or welfare of the public is endangered. A8. Licensees who have knowledge or reason to believe that any person or firm has violated any rules or laws applying to the practice of engineering or surveying shall report it to the board, may report it to appropriate legal authorities, and shall cooperate with the board and those authorities as requested.
NSPE - National Society of Professional Engineers	6 Fundamental Canons, Rules and Obligations [Last update: 2010]	II.1. Engineers shall hold paramount the safety, health, and welfare of the public.	III.2c. Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations.	II.1a. If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate.	II.1a. If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate. II.11. Engineers having knowledge of any alleged violation of this Code shall report thereon to appropriate professional bodies and, when relevant, also to public authorities, and cooperate with the proper authorities in furnishing such information or assistance as may be required. III.2b. Engineers shall not complete, sign, or seal plans and/or specifications that are not in conformity with applicable engineering standards. If the client or employer insists on such unprofessional conduct, they shall notify the proper authorities and withdraw from further service on the project.



A SunCam Online Continuing Education Course

**REFERENCES**

Items in **bold** are highly recommended for in-depth study. **Always use the latest editions.**

- A. Camara, John A. *PE Power Reference Manual*. Belmont, CA: PPI (Kaplan), 2021.
- B. Earley, Mark, ed. *NFPA 70, National Electrical Code Handbook*. Quincy, Massachusetts: NFPA, 2020.

**NOTE**

Electrical refers to something related to electricity while “electric” refers to a device or machine that runs on electricity. Nevertheless, the NEC is sometimes referred to as the National Electric Code. This Handbook with its illustrations, commentaries, and guidance is the best source found for those dealing with the NEC frequently in their projects.

- C. IEEE 315-1975. *Graphic Symbols for Electrical and Electronics Diagrams*. New York: IEEE, approved 1975, reaffirmed 1993.
- D. IEEE 280-2021. *IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering*. New York: IEEE.
- E. Grainger, John J., and William Stevenson, Jr. *Power System Analysis*. New York: McGraw Hill, 1994.
- F. Parker, Sybil P., editor in chief. *McGraw-Hill Dictionary of Scientific and Technical Terms*, 5<sup>th</sup> ed. New York: McGraw-Hill, 1994.
- G. Wildi, Theodore. *Electrical Power Technology*. New York: John Wiley & Sons, 1981.
- H. Lindeburg, Michael R. *Engineer-in-Training Reference Manual*, 8<sup>th</sup> ed. Belmont, CA: Professional Publications, Inc., 1992.**



A SunCam Online Continuing Education Course

**Appendix A: Equivalent Units Of Derived And Common SI Units**

Symbol	Equivalent Units			
A	C/s	W/V	V/Ω	J/(s⋅V)
C	A⋅s	J/V	(N⋅m)/V	V⋅F
F	C/V	C <sup>2</sup> /J	s/Ω	(A⋅s)/V
F/m	C/(V⋅m)	C <sup>2</sup> /(J⋅m)	C <sup>2</sup> /(N⋅m <sup>2</sup> )	s/(Ω⋅m)
H	W/A	(V⋅s)/A	Ω⋅s	(T⋅m <sup>2</sup> )/A
Hz	1/s	s <sup>-1</sup>	cycles/s	radians/(2π⋅s)
J	N⋅m	V⋅C	W⋅s	(kg⋅m <sup>2</sup> )/s <sup>2</sup>
m <sup>2</sup> /s <sup>2</sup>	J/kg	(N⋅m)/kg	(V⋅C)/kg	(C⋅m <sup>2</sup> )/(A⋅s <sup>3</sup> )
N	J/m	(V⋅C)/m	(W⋅C)/(A⋅m)	(kg⋅m)/s <sup>2</sup>
N/A <sup>2</sup>	Wb/(N⋅m <sup>2</sup> )	(V⋅s)/(N⋅m <sup>2</sup> )	T/N	1/(A⋅m)
Pa	N/m <sup>2</sup>	J/m <sup>3</sup>	(W⋅s)/m <sup>3</sup>	kg/(m⋅s <sup>2</sup> )
Ω	V/A	W/A <sup>2</sup>	V <sup>2</sup> /W	(kg⋅m <sup>2</sup> )/(A <sup>2</sup> ⋅s <sup>3</sup> )
S	A/V	1/Ω	A <sup>2</sup> /W	(A <sup>2</sup> ⋅s <sup>3</sup> )/(kg⋅m <sup>2</sup> )
T	Wb/m <sup>2</sup>	N/(A⋅m)	(N⋅s)/(C⋅m)	kg/(A⋅s <sup>2</sup> )
V	J/C	W/A	C/F	(kg⋅m <sup>2</sup> )/(A⋅s <sup>3</sup> )
V/m	N/C	W/(A⋅m)	J/(A⋅m⋅s)	(kg⋅m)/(A⋅s <sup>3</sup> )
W	J/s	V⋅A	V <sup>2</sup> /Ω	(kg⋅m <sup>2</sup> )/s <sup>3</sup>
Wb	V⋅s	H⋅A	T/m <sup>2</sup>	(kg⋅m <sup>2</sup> )/(A⋅s <sup>2</sup> )



A SunCam Online Continuing Education Course

**Appendix B: Physical Constants**

Table Note 1

Quantity	Symbol	US Customary	SI Units
<b>Charge</b>			
electron	$e$		$-1.6022 \times 10^{-19}$ C
proton	$p$		$+1.6022 \times 10^{-19}$ C
<b>Density</b>			
air [STP][32°F, (0°C)]		0.0805 lbm/ft <sup>3</sup>	1.29 kg/m <sup>3</sup>
air [70°F, (20°C), 1 atm]		0.0749 lbm/ft <sup>3</sup>	1.20 kg/m <sup>3</sup>
sea water		64 lbm/ft <sup>3</sup>	1025 kg/m <sup>3</sup>
water [mean]		62.4 lbm/ft <sup>3</sup>	1000 kg/m <sup>3</sup>
<b>Distance</b>			
Earth radius <sup>2</sup>	$\oplus$	$2.09 \times 10^7$ ft	$6.370 \times 10^6$ m
Earth-Moon separation <sup>2</sup>	$\oplus\text{C}$	$1.26 \times 10^9$ ft	$3.84 \times 10^8$ m
Earth-Sun separation <sup>2</sup>	$\oplus\odot$	$4.89 \times 10^{11}$ ft	$1.49 \times 10^{11}$ m
Moon radius <sup>2</sup>	$\text{C}$	$5.71 \times 10^6$ ft	$1.74 \times 10^6$ m
Sun radius <sup>2</sup>	$\odot$	$2.28 \times 10^9$ ft	$6.96 \times 10^8$ m
first Bohr radius	$a_0$	$1.736 \times 10^{-10}$ ft	$5.292 \times 10^{-11}$ m
<b>Gravitational Acceleration</b>			
Earth [mean]	$g$	32.174 (32.2) ft/sec <sup>2</sup>	9.8067 (9.81) m/s <sup>2</sup>
<b>Mass</b>			
atomic mass unit	$\mu$ or $m_\mu$ $\frac{1}{12}m(^{12}\text{C})$	$3.66 \times 10^{-27}$ lbm	$1.6606 \times 10^{-27}$ kg or $10^{-3}$ kg mol <sup>-1</sup> / $N_A$
Earth <sup>2</sup>	$\oplus$	$4.11 \times 10^{23}$ slugs	$6.00 \times 10^{24}$ kg
Earth [customary U.S.] <sup>2</sup>	$\oplus$	$1.32 \times 10^{25}$ lbm	-
Moon <sup>2</sup>	$\text{C}$	$1.623 \times 10^{23}$ lbm	$7.36 \times 10^{22}$ kg
Sun <sup>2</sup>	$\odot$	$4.387 \times 10^{30}$ lbm	$1.99 \times 10^{30}$ kg
electron rest mass	$m_e$	$2.008 \times 10^{-30}$ lbm	$9.1095 \times 10^{-31}$ kg
neutron rest mass	$m_n$	$3.693 \times 10^{-27}$ lbm	$1.6750 \times 10^{-27}$ kg



A SunCam Online Continuing Education Course

proton rest mass	$m_p$	$3.688 \times 10^{-27}$ lbm	$1.6727 \times 10^{-27}$ kg
<b>Pressure</b>			
atmospheric		14.696 (14.7) lbf/in <sup>2</sup>	$1.0133 \times 10^5$ Pa
<b>Temperature</b>			
standard		32° F (492° R)	0° C (273 K)
absolute zero		-459.67° F (0° R)	-273.16° C (0 K)
<b>Velocity<sup>3</sup></b>			
Earth escape		$3.67 \times 10^4$ ft/sec	$1.12 \times 10^4$ m/s
light (vacuum)	$c, c_0$	$9.84 \times 10^8$ ft/sec	$2.9979 (3.00) \times 10^8$ m/s
sound [air, STP]	$a$	1090 ft/sec	331 m/s
sound [air, 70°F, (20°C), 1 atm]		1130 ft/sec	344 ft/s
<b>Volume</b>			
Volume: molal ideal gas (STP) <sup>4</sup>		359 ft <sup>3</sup> / lbmol	22.41 m <sup>3</sup> /kmol

Table 1 Notes

1. Units come from a variety of sources, but primarily from the Handbook of Chemistry and Physics, The Standard Handbook for Aeronautical and Astronautical Engineers, and the Electrical Engineering Reference Manual for the PE Exam. See also the NIST website at <https://pml.nist.gov/cuu/Constants/>.
2. Symbols shown for the solar system are those used by NASA. See <https://science.nasa.gov/resource/solar-system-symbols/>.
3. Velocity technically is a vector. It has direction.
4. The unit “lbmol” is an actual unit, not a misspelling.



A SunCam Online Continuing Education Course

**Appendix C: Fundamental Constants**

Quantity	Symbols	US Customary	SI Units
Avogadro's number	$N_A, L$		$6.022 \times 10^{23} \text{ mol}^{-1}$
Bohr magneton	$\alpha_B$		$9.2732 \times 10^{-24} \text{ J/T}$
Boltzmann constant	$\kappa$	$5.65 \times 10^{-24} \text{ ft-lbf/}^\circ\text{R}$	$1.3805 \times 10^{-23} \text{ J/T}$
electron volt: $\left(\frac{e}{C}\right) \text{ J}$	eV		$1.602 \times 10^{-19} \text{ J}$
Faraday constant, $N_A e$	F		96485 C/mol
fine structure constant, inverse $\alpha^{-1}$	$\alpha$ $\alpha^{-1}$		$7.297 \times 10^{-3}$ ( $\approx 1/137$ ) 137.035
gravitational constant	$g_c$	$32.174 \text{ lbm-ft/lbf-sec}^2$	
Newtonian gravitational constant	G	$3.44 \times 10^{-8} \text{ ft}^4 / \text{lbf-sec}^4$	$6.672 \times 10^{-11} \text{ N m}^2 / \text{kg}^2$
nuclear magneton	$\alpha_N$		$5.050 \times 10^{-27} \text{ J/T}$
permeability of a vacuum	$\mu_0$		$1.2566 \times 10^{-6} \text{ N/A}^2 \text{ (H/m)}$
permittivity of a vacuum, electric constant $1 / \mu_0 c^2$	$\epsilon_0$		$8.854 \times 10^{-12} \text{ C}^2 / \text{N m}^2 \text{ (F/m)}$
Planck's constant	h		$6.6256 \times 10^{-34} \text{ J s}$
Planck's constant: $h/2\pi$	$\hbar$		$1.0546 \times 10^{-34} \text{ J s}$
Rydberg constant	$R_\infty$		$1.097 \times 10^7 \text{ m}^{-1}$
specific gas constant, air	R	$53.3 \text{ ft-lbf/lbm-}^\circ\text{R}$	$287 \text{ J/kg K}$
Stefan-Boltzmann constant		$1.71 \times 10^{-9} \text{ BTU/ft}^2 \text{-hr-}^\circ\text{R}^4$	$5.670 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$
triple point, water		$32.02^\circ\text{F}, 0.0888 \text{ psia}$	$0.01109^\circ\text{C}, 0.6123 \text{ kPa}$
universal gas constant	$R^*$	$1545 \text{ ft-lbf/lbmol-}^\circ\text{R}$ $1.986 \text{ BTU/lbmol-}^\circ\text{R}$	$8314 \text{ J/kmol K}$

Table Notes

1. Units come from a variety of sources, but primarily from the Handbook of Chemistry and Physics, The Standard Handbook for Aeronautical and Astronautical Engineers, and the Electrical Engineering Reference Manual for the PE Exam. See also the NIST website at <https://pml.nist.gov/cuu/Constants/>. The unit in Volume of "lbmol" is an actual unit, not a misspelling.



A SunCam Online Continuing Education Course

**Appendix D: Mathematical Constants, Signs/Symbols, Maxwell's Equations**

Quantity	Symbol	Value
Archimedes' constant (pi)	$\pi$	3.1415926536
base of natural logs	$e$	2.7182818285
Euler's constant	$C$ or $\tau$	0.5772156649

Signs/Symbols	Meaning
$\cdot$	multiplied by
$/$	divided by
$:$	ratio
$\gg$	much greater than
$\ll$	much less than
$=$	equals
$\equiv$	identical with
$\sim$	similar to
$\approx$	approximately equals
$\cong$	approximately equals, congruent
$\rightarrow, \dot{=}$	approaches
$\propto$	proportional, varies as
$\therefore$	therefore

**Maxwell's Equations**

integral form	point form	remarks
$\oint_s \mathbf{D} \cdot d\mathbf{s} = \int_V \rho \, dv$	$\nabla \cdot \mathbf{D} = \rho$	Gauss' law
$\oint_s \mathbf{B} \cdot d\mathbf{s} = 0$	$\nabla \cdot \mathbf{B} = 0$	nonexistence of magnetic monopoles
$\oint \mathbf{E} \cdot d\mathbf{l} = \int_s \left( \frac{-\partial \mathbf{B}}{\partial t} \right) \cdot d\mathbf{s}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	Faraday's law
$\oint \mathbf{H} \cdot d\mathbf{l} = \int_s \left( \mathbf{J}_c + \frac{\partial \mathbf{D}}{\partial t} \right) \cdot d\mathbf{s}$	$\nabla \times \mathbf{H} = \mathbf{J}_c + \frac{\partial \mathbf{D}}{\partial t}$	Ampère's law

**Free-Space Form**

integral form	point form
$\oint_s \mathbf{D} \cdot d\mathbf{s} = 0$	$\nabla \cdot \mathbf{D} = 0$
$\oint_s \mathbf{B} \cdot d\mathbf{s} = 0$	$\nabla \cdot \mathbf{B} = 0$
$\oint \mathbf{E} \cdot d\mathbf{l} = \int_s \left( \frac{-\partial \mathbf{B}}{\partial t} \right) \cdot d\mathbf{s}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\oint \mathbf{H} \cdot d\mathbf{l} = \int_s \left( \frac{\partial \mathbf{D}}{\partial t} \right) \cdot d\mathbf{s}$	$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t}$

**Electromagnetic Field Vector Equations**

$$\mathbf{D} = \epsilon \mathbf{E} = \epsilon_0 \mathbf{E} + \mathbf{P} = \epsilon_0(1 + \chi_e) \mathbf{E}$$

$$\mathbf{B} = \mu \mathbf{H} = \mu_0 \mathbf{H} + \mu_0 \mathbf{M} = \mu_0(1 + \chi_m) \mathbf{H}$$

$$\mathbf{J} = \sigma \mathbf{E} = \rho \mathbf{v}$$



## A SunCam Online Continuing Education Course

**Appendix E: The Greek Alphabet**

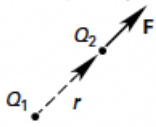
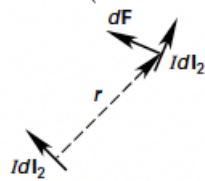
A	$\alpha$	alpha	N	$\nu$	nu
B	$\beta$	beta	$\Xi$	$\xi$	xi
$\Gamma$	$\gamma$	gamma	O	$o$	omicron
$\Delta$	$\delta$	delta	$\Pi$	$\pi$	pi
E	$\varepsilon$	epsilon	P	$\rho$	rho
Z	$\zeta$	zeta	$\Sigma$	$\sigma$	sigma
H	$\eta$	eta	T	$\tau$	tau
$\Theta$	$\theta$	theta	$\Upsilon$	$\upsilon$	upsilon
I	$\iota$	iota	$\Phi$	$\phi$	phi
K	$\kappa$	kappa	X	$\chi$	chi
$\Lambda$	$\lambda$	lambda	$\Psi$	$\psi$	psi
M	$\mu$	mu	$\Omega$	$\omega$	omega

**Appendix F: SI Prefixes**

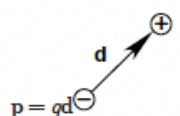
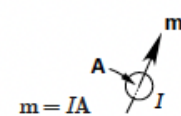
<u>symbol</u>	<u>prefix</u>	<u>value</u>
a	atto	$10^{-18}$
f	femto	$10^{-15}$
p	pico	$10^{-12}$
n	nano	$10^{-9}$
$\mu$	micro	$10^{-6}$
m	milli	$10^{-3}$
c	centi	$10^{-2}$
d	deci	$10^{-1}$
da	deka	10
h	hecto	$10^2$
k	kilo	$10^3$
M	mega	$10^6$
G	giga	$10^9$
T	tera	$10^{12}$
P	peta	$10^{15}$
E	exa	$10^{18}$

A SunCam Online Continuing Education Course

**Appendix G: Comparison of Electric & Magnetic Equations**

equation description	electric version	magnetic version	remarks
experimental force law	<p>Coulomb's law</p> $\mathbf{F} = \frac{Q_1 Q_2}{4\pi\epsilon r^2} \mathbf{r}$ 	<p>force between two current elements</p> $d\mathbf{F} = \left( \frac{\mu_0}{4\pi} \right) \left( \frac{I_2 d\mathbf{l}_2}{r^2} \times (I_1 d\mathbf{l}_1 \times \mathbf{r}) \right)$ 	<p>The term <math>I dl</math> in the magnetic column is the equivalent of a "magnetic charge" <math>q_m</math>. The <math>I</math> or the <math>dl</math> can be the vector. The <math>r</math> is a unit vector pointing from 1 to 2.</p>
field definitions from force law	$\mathbf{F} = q\mathbf{E}$	$d\mathbf{F} = \mathbf{I} \times \mathbf{B} dl$ current element $d\mathbf{F} = \mathbf{J} \times \mathbf{B} dV$ distributed current element $d\mathbf{F} = q \mathbf{v} \times \mathbf{B}$ moving charge	<p>The <math>V</math> used in this row represents volume, not voltage. The <math>v</math> is the velocity.</p>
general force law	$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ $d\mathbf{F} = (\rho \mathbf{E} + \mathbf{J} \times \mathbf{B}) dV \text{ where } dQ = \rho dV$		<p>The <math>V</math> in this row represents the volume, not voltage. The <math>v</math> is the velocity.</p>
definition of scalar and vector potential	$\mathbf{E} = -\nabla V$	$\mathbf{B} = \nabla \times \mathbf{A}$	<p><math>\mathbf{A}</math> is the magnetic vector potential.</p>
Poisson's equation for the potential function	$\nabla^2 V = -\frac{\rho}{\epsilon}$	$\nabla^2 \mathbf{A} = -\mu_0 \mathbf{J}$	<p>From a knowledge of the charge distribution, the potential can be found and then the <math>\mathbf{E}</math> and <math>\mathbf{B}</math> fields determined.</p>
Gauss's law enclosing charge and Ampère's law enclosing current	$\iint \mathbf{D} \cdot d\mathbf{A} = \iiint \rho dV = Q$ $\nabla \cdot \mathbf{D} = \rho$	$\oint \mathbf{H} \cdot d\mathbf{l} = I$ $\nabla \times \mathbf{H} = \mathbf{J}$	<p>The <math>V</math> in this row represents volume.</p>
constitutive relations	$\mathbf{D} = \epsilon \mathbf{E}$ $\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P}$	$\mathbf{B} = \mu \mathbf{H}$ $\mathbf{B} = \mu_0 \mathbf{H} + \mu_0 \mathbf{M}$	<p>The second set of equations is always valid. The first set assumes the medium is linear and isotropic.</p>
definitions of relative permittivity and permeability	$\epsilon_r = \frac{\epsilon}{\epsilon_0}$ $\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$	$\mu_r = \frac{\mu}{\mu_0}$ $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$	

## A SunCam Online Continuing Education Course

equation description	electric version	magnetic version	remarks
capacitance and inductance of a field cell	$\epsilon_0 = \frac{C}{l}$	$\mu_0 = \frac{L}{l}$	Field cells are a construct designed to represent free space in terms of a parallel plate capacitor and an inductor. This capacitance and inductance exist regardless of the presence of an electric or magnetic field.
capacitance and inductance	$C = \frac{Q}{V}$	$L = \frac{\Lambda}{I}$	$\Lambda$ is the flux linkage.
energy density of a field	$U = \frac{1}{2} \epsilon E^2$	$U = \frac{1}{2} \mu H^2$	Both energy and momentum are carried by a field.
energy stored by capacitance and inductance	$W = \frac{1}{2} CV^2$	$W = \frac{1}{2} LI^2$	
electromotive and magnetomotive force with sources present	$\oint \mathcal{E} \cdot d\mathbf{l} = \mathcal{E} = V$	$\oint \mathbf{H} \cdot d\mathbf{l} = NI = F_m = V_m$	The $\mathcal{E}$ is the emf, not the permittivity. Without sources present, both line integrals are equal to zero.
dipole moments	 $\mathbf{p} = q\mathbf{d}$	 $\mathbf{m} = I\mathbf{A}$	
dipole torque	$\mathbf{T} = \mathbf{p} \times \mathbf{E}$	$\mathbf{T} = \mathbf{m} \times \mathbf{B}$	This torque occurs due to the dipole being immersed in an external $\mathbf{E}$ or $\mathbf{B}$ field.
dipole potential energy	$W = -\mathbf{p} \cdot \mathbf{E}$	$W = -\mathbf{m} \cdot \mathbf{B}$	

electric

$$\text{emf} = V = IR$$

 current  $I$ 

 emf  $\mathcal{E}$  or  $V$ 

$$\text{resistance } R = \rho l/A = l/\sigma A$$

 resistivity  $\rho$ 

$$\text{conductance } G = 1/R$$

$$\text{conductivity } \sigma = 1/\rho$$

magnetic

$$\text{mmf} = V_m = \phi \mathcal{R}$$

 flux  $\phi$ 

 mmf  $V_m$ 

$$\text{reluctance } \mathcal{R} = l/\mu A$$

 reluctivity  $1/\mu$ 

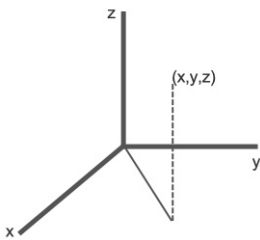
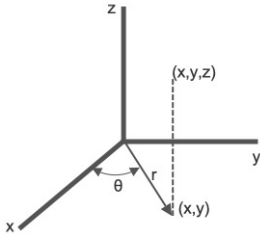
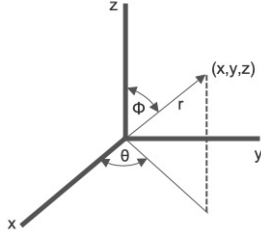
$$\text{permeance } P_m = \mu A/l$$

 permeability  $\mu$



A SunCam Online Continuing Education Course

**Appendix H: Coordinate Systems and Related Operations**

Mathematical Operations	Rectangular Coordinates	Cylindrical Coordinates	Spherical Coordinates
Conversion to Rectangular Coordinants	 $x = x$ $y = y$ $z = z$	 $x = r \cos \theta$ $y = r \sin \theta$ $z = z$	 $x = r \sin \phi \cos \theta$ $y = r \sin \phi \sin \theta$ $z = r \cos \phi$
Gradient	$\nabla f = \frac{\partial f}{\partial x} \mathbf{i} + \frac{\partial f}{\partial y} \mathbf{j} + \frac{\partial f}{\partial z} \mathbf{k}$	$\nabla f = \frac{\partial f}{\partial r} \mathbf{r} + \frac{1}{r} \frac{\partial f}{\partial \theta} \boldsymbol{\theta} + \frac{\partial f}{\partial z} \mathbf{k}$	$\nabla f = \frac{\partial f}{\partial r} \mathbf{r} + \frac{1}{r} \frac{\partial f}{\partial \phi} \boldsymbol{\phi} + \frac{1}{r \sin \theta} \frac{\partial f}{\partial \theta} \boldsymbol{\theta}$
Divergence	$\nabla \cdot \mathbf{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$	$\nabla \cdot \mathbf{A} = \frac{1}{r} \frac{\partial (r A_r)}{\partial r} + \frac{1}{r} \frac{\partial A_\theta}{\partial \theta} + \frac{\partial A_z}{\partial z}$	$\nabla \cdot \mathbf{A} = \frac{1}{r^2} \frac{\partial (r^2 A_r)}{\partial r} + \frac{1}{r \sin \phi} \frac{\partial (A_\phi \sin \phi)}{\partial \phi} + \frac{1}{r \sin \phi} \frac{\partial A_\theta}{\partial \theta}$
Curl	$\nabla \times \mathbf{A} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$	$\nabla \times \mathbf{A} = \begin{vmatrix} \frac{1}{r} \mathbf{r} & \boldsymbol{\theta} & \frac{1}{r} \mathbf{k} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \theta} & \frac{\partial}{\partial z} \\ A_r & A_\theta & A_z \end{vmatrix}$	$\nabla \times \mathbf{A} = \begin{vmatrix} \frac{1}{r^2 \sin \theta} \mathbf{r} & \frac{1}{r^2 \sin \theta} \boldsymbol{\phi} & \frac{1}{r} \boldsymbol{\theta} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial \theta} \\ A_r & r A_\phi & r A_\theta A_\phi \end{vmatrix}$
Laplacian	$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2}$	$\nabla^2 f = \frac{1}{r} \frac{\partial r}{\partial r} \left( r \frac{\partial f}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 f}{\partial \theta^2} + \frac{\partial^2 f}{\partial z^2}$	$\nabla^2 f = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial f}{\partial r} \right) + \frac{1}{r^2 \sin \phi} \frac{\partial}{\partial \phi} \left( \sin \phi \frac{\partial f}{\partial \phi} \right) + \frac{1}{r^2 \sin^2 \phi} \left( \frac{\partial^2 f}{\partial \theta^2} \right)$