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Prof. Dr. Ettore Segreto

Desenvolvimento do sistema de controle lento para a instalação de ensaio do dispositivo Arapuca

Resumo dos objetivos

Este projeto busca a concepção de uma instalação para se testar o protótipo que será feito em um ambiente criogênico (temperatura do argônio líquido^[1]). A instalação terá um sistema de resfriamento, sensores medidores de nível, medidores de pressão, válvulas remotas, isolamento dinâmico de vácuo e sistemas de calibração à laser para o dispositivo fotônico.

Para uma operação e funcionamento eficiente da instalação é mandatório o desenvolvimento de um sistema de controle lento (Slow Control System – SCS^[2]) que monitore e controle todos os parâmetros relevantes. Além disso, o criostato, funcionando em uma temperatura de, aproximadamente, 89K, pode representar um risco potencial, pois se a temperatura sair do controle o aumento da pressão associado pode causar problemas graves. Por este motivo o sistema de controle lento (SCS) deve ser capaz de alertar os pesquisadores de plantão e os especialistas de plantão a distancia através de sms e e-mails.

O SCS deve guardar informações sobre os alarmes e ter uma página dedicada a registros eletrônicos. Se planeja utilizar o software LabVIEW^[3] para se construir o sistema de controle.

Introdução

Inicialmente busco criar o sistema de controle lento do medidor de pressão PKR 251 Compact FullRange™ Gauge, FPM Sealed da PFEIFFER VACUUM^[4] que será utilizado no experimento, dado que o software deste sistema servirá de base para todos os outros sistemas utilizados.

Metodologia

O problema foi dividido em sete partes:

Hardware

- Hardware de medição física: O hardware utilizado para se medir as propriedades físicas desejadas, neste caso, o medidor de pressão;

- Hardware de medição elétrica: O hardware utilizado para medir a diferença de potencial fornecida pelo medidor de pressão;

- Hardware de alimentação: O hardware necessário para se fornecer a voltagem e corrente apropriada para o funcionamento dos hardwares de medição;

- Hardware de comunicação: O hardware que passa a informação adquirida pelo Hardware de medição elétrica para o software.

Software

- Software de recepção: A parte do programa que recebe as informações do hardware de comunicação;

- Software de conversão: A parte do programa que transforma os valores de voltagem em valores de pressão;

- Software de Análise: A parte do programa que executa todas as tarefas descritas no resumo;

Resultados

Hardware

Hardware de medição física:

O hardware de medição física será o PKR 251 Compact FullRange™ Gauge, FPM Sealed da PFEIFFER VACUUM^[4]. Este equipamento tem um alcance de 5×10^{-9} mbar à 1000 mbar^[5], sendo composto de dois sistemas de medições, o pirani^[6], que está sempre em funcionamento, e o catodo frio^[7], que é controlado pelo pirani e somente ativado para pressões abaixo de 1×10^{-2} mbar^[5].

Este hardware mede a pressão no experimento e devolve a mesma como um sinal elétrico entre 0 e 10V



Fig 1. PKR 251 Compact FullRange™ Gauge, FPM Sealed da PFEIFFER VACUUM¹

Hardware de medição elétrica:

Para a medição elétrica utilizarei uma placa Arduino UNO^[5], a qual será conectada no hardware de medição física com o intuito de se medir a voltagem fornecida pelo medidor de pressão.

Arduino é uma plataforma eletrônica open-source que é capaz de ler entradas em geral, fazer o processamento das mesmas e devolver saídas através de um microcontrolador presente na placa o qual utiliza a linguagem de programação própria do Arduino (Arduino programming language) e o software próprio do mesmo (Arduino Software (IDE)).^[10]

Do ponto de vista de hardware, o Arduino será utilizado como um voltímetro, porém dado que este só consegue medir de 0 à 5 V utilizarem um divisor de voltagem para conseguirmos medir o range de 0 à 10 V fornecido pelo hardware de medição física. Me limitarei a este range pois o Arduino só consegue ler 1024 níveis diferentes e portanto quanto

maior o range utilizado menor a precisão que teremos.

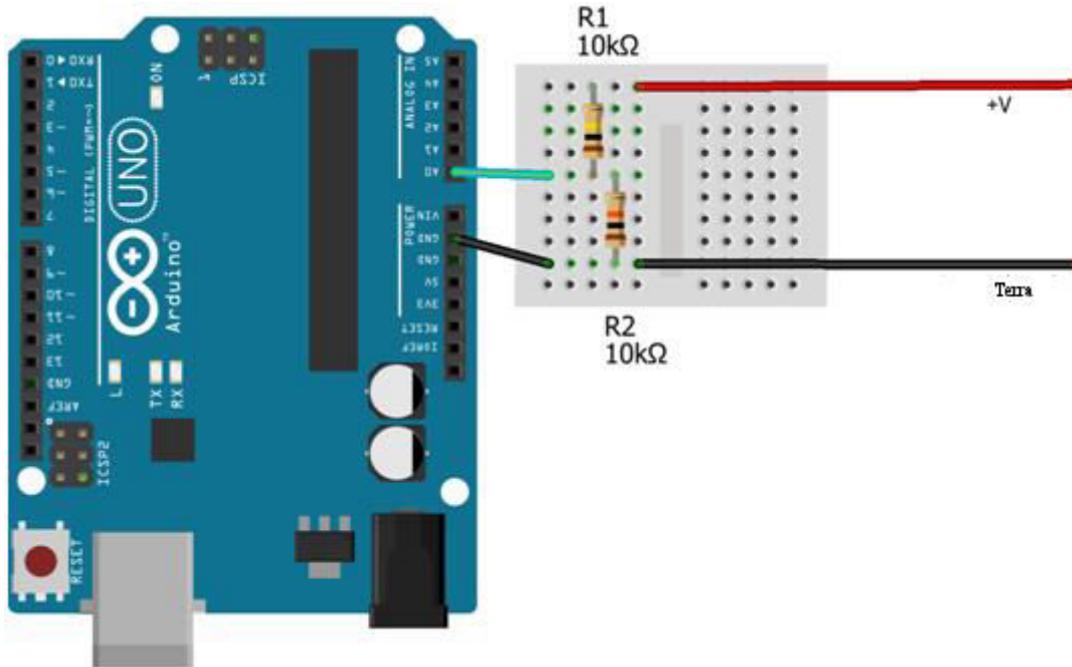


Fig 2. Circuito do Hardware de medição elétrica.

Do ponto de vista de software, utilizaremos o seguinte código^[11] no Arduino Software (IDE), escrito na linguagem própria do Arduino.

```
float vPow = 4.7;

float r1 = 100000;

float r2 = 10000;

void setup() {

  Serial.begin(9600);

  // Send ANSI terminal codes

  Serial.print("\x1B");

  Serial.print("[2J");

  Serial.print("\x1B");

  Serial.println("[H");

  // End ANSI terminal codes
```

```
Serial.println("-----");

Serial.println("DC VOLTMETER");

Serial.print("Maximum Voltage: ");

Serial.print((int)(vPow / (r2 / (r1 + r2))));

Serial.println("V");

Serial.println("-----");

Serial.println("");

delay(2000);

}

void loop() {

float v = (analogRead(0) * vPow) / 1024.0;

float v2 = v / (r2 / (r1 + r2));

// Send ANSI terminal codes

Serial.print("\x1B");

Serial.print("[1A");

// End ANSI terminal codes

Serial.println(v2);

}
```

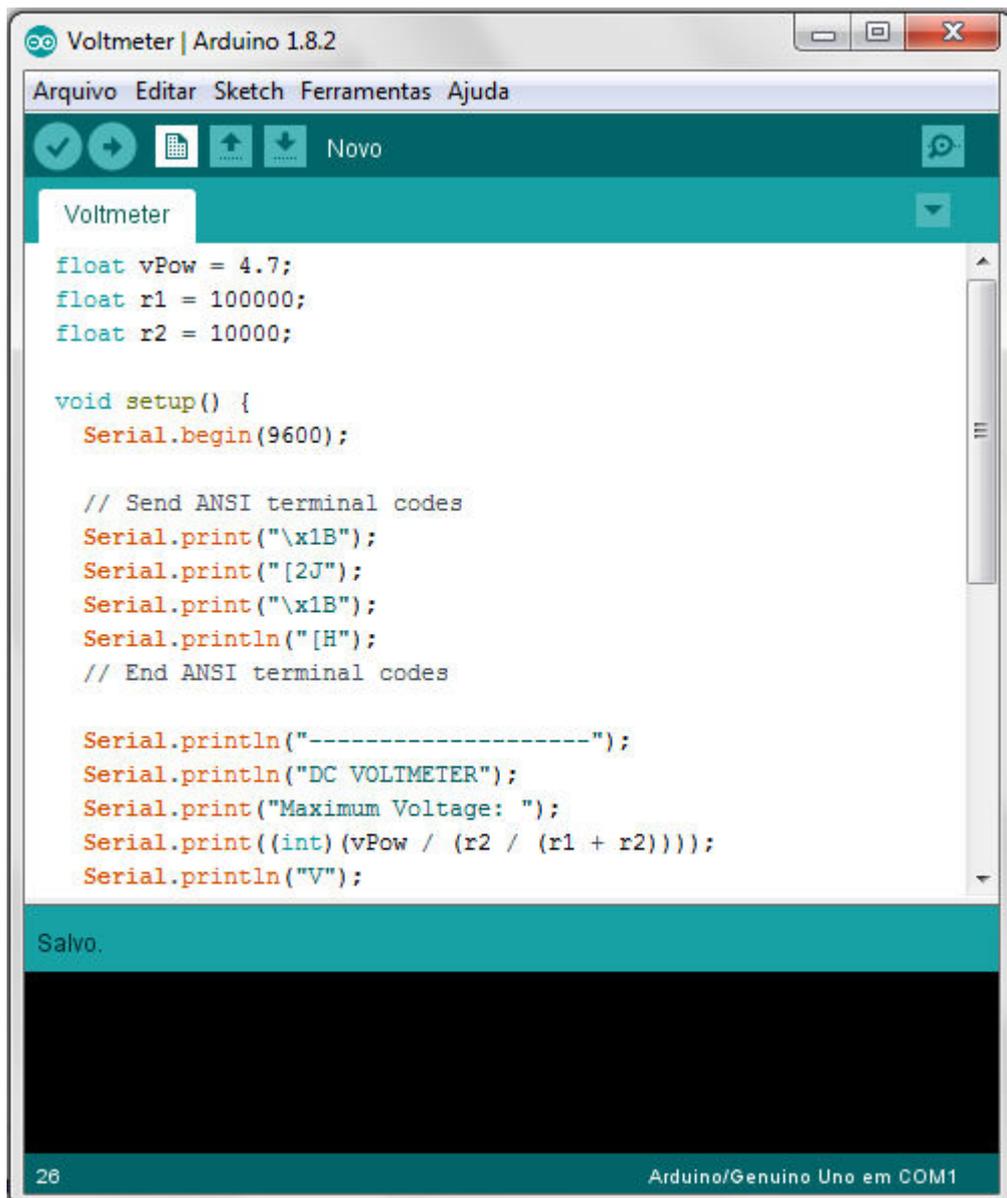


Fig 3 – Interface do Arduino Software (IDE)

Hardware de alimentação:

O PKR 251 apresenta o seguinte conector:



Fig 4. Conector do PKR 251

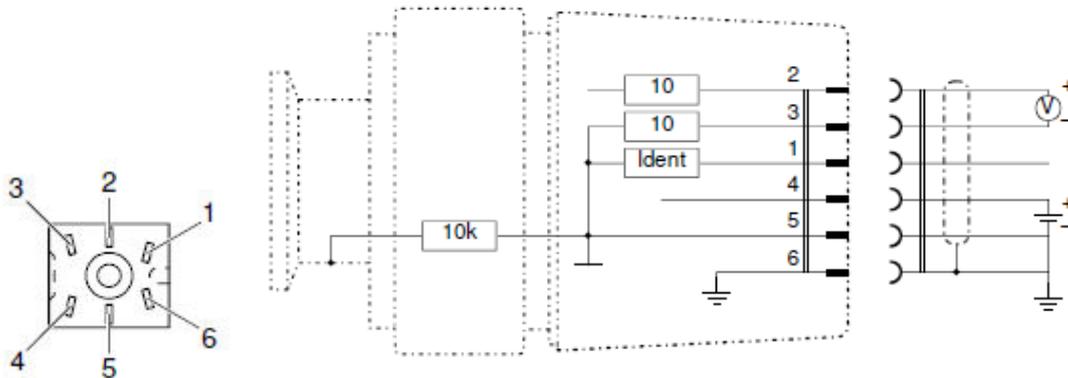


Fig 5. À direita, os seis pinos o conector. À esquerda as conexões internas de cada pino.^[8]

A função de cada um desses pinos é^[8]:

- 1- Identificação
- 2- Saída de Sinal
- 3- Terra da saída
- 4- Fornecimento elétrico
- 5- Terra do fornecimento elétrico
- 6- Blindagem elétrica

O pino 1 não será utilizado, pois ele é utilizado somente quando se usa um leitor da PFEIFFER.

O Hardware de medição elétrica será conectado nos pinos 2 e 3.

No pino 4, 5 e 6 será conectada uma fonte DC de 25 V com uma corrente máxima de 1 A.

Já para o Arduino UNO conectarei uma fonte DC de 12V, 250mA, com pino central positivo em sua entrada de energia.^[9]

Hardware de comunicação:

A comunicação será a própria placa Arduino através de um cabo USB, que conectará a placa ao computador que rodará o Software.

Software

O software de recepção foi realizado no LabVIEW, utilizando-se a interface LabVIEW para Arduino que permite a comunicação entre o software do LabVIEW e do Arduino.

O LabVIEW é um ambiente de desenvolvimento integrado que se utiliza de uma linguagem de gráfica de programação baseada em fluxo de data (G) ao invés de linhas de código.^[6]

Software de recepção:

O código do software de recepção é exibido a seguir:

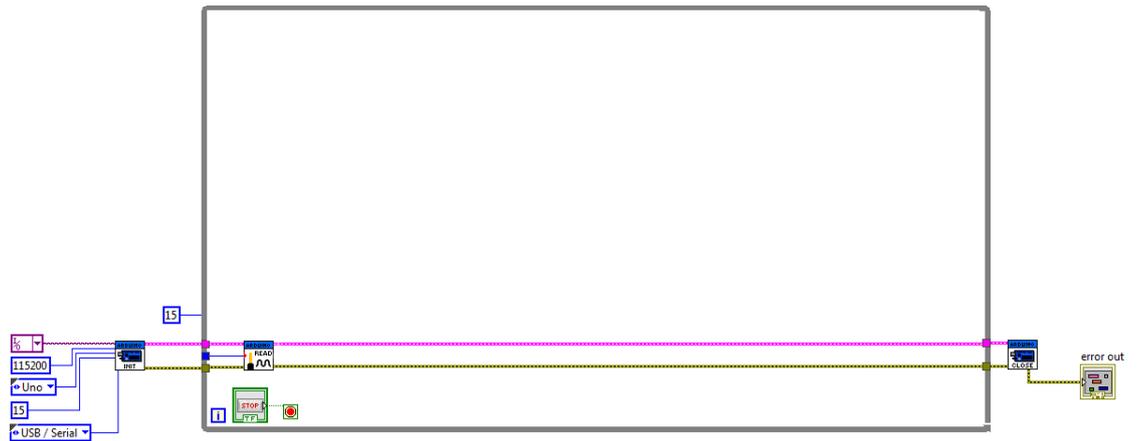


Fig 6. Código do software de recepção no LabVIEW.

Software de análise:

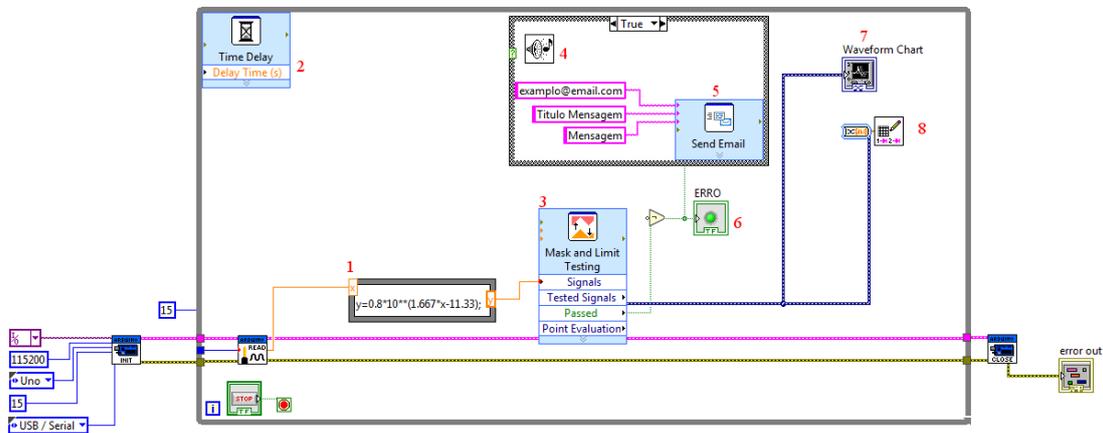


Fig 7: Código do software completo no LabVIEW; Estão numerados os elementos do código de análise.

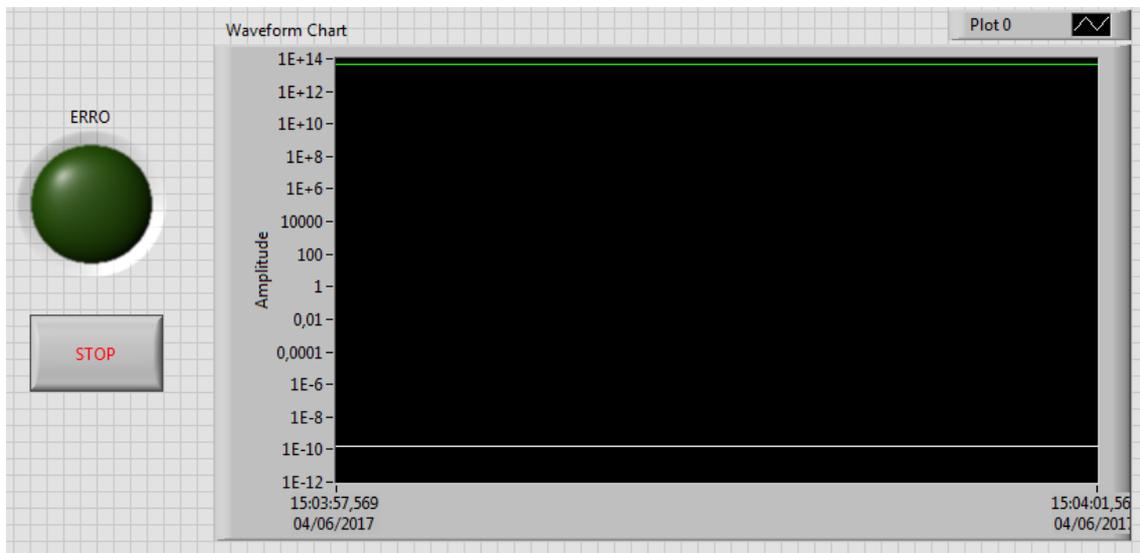


Fig 8: Interface do usuário.

1. Elemento que converte o valor da corrente recebida no valor de pressão correspondente conforme a expressão dada pelo manual do medidor de pressão ^[12] para o argônio.
2. Elemento que faz com que o código se repita a cada segundo.
3. Elemento que detecta se alguma medida ultrapassa os limites superiores e inferiores definidos.
4. Elemento que emite um som caso os limites sejam ultrapassados.
5. Elemento que envia um email caso os limites sejam ultrapassados
6. Elemento que emite acende caso os limites sejam ultrapassados
7. Elemento que exhibe os dados adquiridos em função do tempo na interface do usuário.
8. Elemento que registra os dados medidos em uma planilha do excel

Referências

- [1] Richard B. Stewart; Richard T. Jacobsen. Thermodynamic Properties of Argon from the Triple Point to 1200K with Pressures to 1000 MPa. Center for Applied Thermodynamics Studies, College of Engineering, University of Idaho, Moscow, Idaho 83843, 1988. pag 640. Disponível em: <<https://www.nist.gov/sites/default/files/documents/srd/jpcrd363.pdf>> Acesso em 4 de junho 2017.
- [2] Slow Control System, MIDAS. Disponível em: <https://midas.triumf.ca/MidasWiki/index.php/Slow_Control_System> Acesso em 4 de junho 2017.
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- [5] PFEIFFER VACUUM. “Operating Instructions PKR 251 Compact FullRange® Gauge, FPM sealed.” Pagina 13.
- [6] A. Ellett, R. M. Zabel. “The Pirani Gauge for the Measurement of Small Changes of Pressure”
- [7] G.K.T. Conn., H.N. Daghish. “Cold cathode ionisation gauges for the measurement of low pressures”
- [8] PFEIFFER VACUUM. “Operating Instructions PKR 251 Compact FullRange® Gauge, FPM sealed.” Pagina 12
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- [11] Jennifer Marsh. Building an Arduino DC Voltmeter. Disponível em: < <https://blog.udemy.com/arduino-voltmeter/>> . Acesso em 30 de abril de 2017
- [12] PFEIFFER VACUUM. “Operating Instructions PKR 251 Compact FullRange® Gauge, FPM sealed.” Paginas 24 à 26

Meu orientador concorda com o expressado neste relatório parcial e deu a seguinte opinião:

The work done by Glauber up to now is excellent and in line with the initial plan. He is demonstrating great independence and he is facing problems with elasticity and with an open minded attitude. His work will be the basis to build the slow control system of the ARAPUCA cryogenic test facility in the renewed Laboratorio de Leptons. In this facility, the prototypes of the ARAPUCA devices will be tested in a liquid argon environment. The ARAPUCA is a newly developed device to detect liquid argon scintillation in large liquid argon time projection chambers, like the ones of the Deep Underground Neutrino Experiment (DUNE).

Prof. Ettore Segreto

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Nomenclature

Symbol	Physical quantity	Unit
T	Temperature	K
P	Pressure	MPa
ρ	Density	mol/dm ³
v	Molar volume	dm ³ /mol
Z	Compressibility factor, $Z = P/\rho RT$	
U	Internal energy	J/mol
A	Helmholtz energy	J/mol
G	Gibbs energy	J/mol
H	Enthalpy	J/mol
S	Entropy	J/(mol K)
C_p	Isobaric heat capacity	J/(mol K)
C_v	Isochoric heat capacity	J/(mol K)
C_s	Saturation heat capacity	J/(mol K)
γ	Heat capacity ratio, $\gamma = C_p/C_v$	
W	Velocity of sound	m/s
B	Second virial coefficient	dm ³ /mol
C	Third virial coefficient	(dm ³ /mol) ²
D	Fourth virial coefficient	(dm ³ /mol) ³
$(\partial F/\partial \rho)_T$	Isobaric derivative	dm ³ MPa/mol
$(\partial P/\partial T)_\rho$	Isochore derivative	MPa/K
R	Gas constant (8.314 34)	J/(mol K)
M	Molecular weight of argon (39.948)	
α	Reduced Helmholtz energy, $\alpha = A/RT$	
τ, Θ	Reduced temperature, $\tau = T_c/T$ (or as noted in the text)	
δ	Reduced density, $\delta = \rho/\rho_c$	
POS	Points off scale	
<u>Superscript</u>		
	Ideal gas property	
<u>Subscripts</u>		
0	Reference state property	
c	Critical-point property	
σ	Property at saturation	
tp	Triple point property	
eqn	Calculated using an equation	
data	Experimental value	
max	Calculated from Eq. (10) using the Maxwell Criteria	
nbp	Normal boiling point	
SV	Saturated vapor	
SL	Saturated liquid	
tpv	Triple point (vapor)	
tpl	Triple point (liquid)	
<u>Additional abbreviations</u>		
exp	Exponential function	
Δ	Difference	

Fixed Points for Argon

Symbol	Quantity	Value
T_c	Critical temperature	150.6633 K
P_c	Critical pressure	4.860 MPa
ρ_c	Critical density	13.29 mol/dm ³
T_{tp}	Triple point temperature	83.804 K
P_{tp}	Triple point pressure	0.068 95 MPa
ρ_{tpv}	Triple point density (vapor)	0.101 52 mol/dm ³
ρ_{tpl}	Triple point density (liquid)	35.475 mol/dm ³
T_{nbp}	Normal boiling point temperature	87.293 K
ρ_{nbpv}	Normal boiling density (vapor)	0.145 mol/dm ³
ρ_{nbpl}	Normal boiling density (liquid)	34.95 mol/dm ³
T_0	Reference temperature	298.15 K
H_0^s	Reference enthalpy at T_0	6197 J/mol
S_0^s	Reference entropy at T_0	154.732 (J/mol K)
P_0	Reference pressure	0.101 325 MPa

Slow Control System

From MidasWiki

- Midas Doc
- Feature Listing
- Application Listing
- Online Database
- Index

Contents

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- 2 Introduction
- 3 MIDAS Slow Control System
 - 3.1 Example of a Slow Control Equipment in ODB
 - 3.2 Slow Control Frontend
 - 3.2.1 Example of Equipment Declaration
 - 3.2.2 Example of readout routine
 - 3.3 Multithreaded Slow Control Frontends

Links

- Frontend user code
- Equipment List Parameters
-

Introduction

Slow Control Systems are used for setup and monitoring of hardware that is not time-critical, and can be run at a low priority. Slow Control systems in a typical experiment are often used to setup and/or monitor components such as high voltage modules, temperature sensors, pressure gauges, leak detectors, RF generators, PID controllers etc. often from a large number of hardware vendors.

Examples of Device and Class Drivers can be found under \$MIDASSYS/drivers, and templates for slow control frontends are also available in the MIDAS package - see Frontend templates.

MIDAS Slow Control System

In the Midas Slow Control System, instead of talking directly to each other, Frontend and control programs exchange information through the ODB. If several types of hardware are to be included in a Slow Control System, they may be assigned to a separate Slow Control Equipments. Each Slow Control Equipment is assigned a corresponding ODB subtree under */Equipment*. This tree contains variables needed to control the equipment as well as variables measured by the equipment.

In the case of a high voltage equipment this is

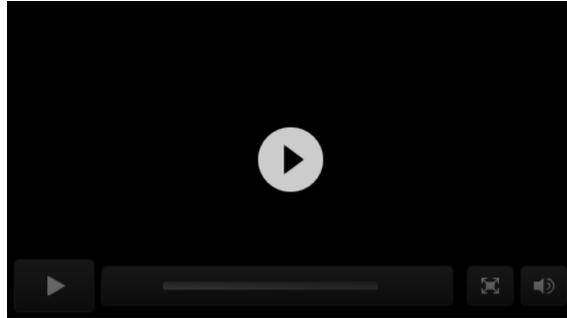
- a Demand array which contains voltages to be set,
- a Measured array which contains read back voltages and
- a Current array which contains the current drawn from each channel.

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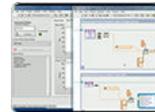
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Products / Measurement / ActiveLine / ActiveLine Gauges / PKR 251, FPM sealed, DN 40 CF-F



PKR 251, FPM sealed, DN 40 CF-F

Overview

- Flange size: DN 40 CF-F
- Maximum pressure refers to inert gases and temperatures of less than 55 °C
- Corrosion-resistant

Product view



Order number: PT R26 002

[Similar Image](#)

Technical data

Accuracy: $1 \cdot 10^{-8} - 1 \cdot 100$ hPa ± 30 %

Anode	Molybdenum
Bakeout temperature	Electronic removed, ≤ 150 °C
Feature	Interior FPM sealed
Feedthrough	Al ₂ O ₃ , Glas
Filament	Tungsten
Flange, Material	Stainless steel
Measurement range max.	1 · 10 ³ hPa 7.5 · 10 ² Torr 1 · 10 ³ mbar
Measurement range min.	5 · 10 ⁻⁹ hPa 3.75 · 10 ⁻⁹ Torr 5 · 10 ⁻⁹ mbar
Method of measurement	Pirani/Cold Cathode
Nominal diameter	DN 40 CF-F
Output signal: Measurement range	1.8 – 8.6 V
Output signal: Minimum load	10 kΩ
Repeatability: 1 · 10 ⁻⁸ – 100 hPa	± 5 %
Seal	FPM
Supply: Power consumption max.	2 W
Supply: Voltage	15-30 V DC
Temperature: Operating	5 – 55 °C
Temperature: Storage	-40 – 65 °C
Volume	20 cm ³
Weight	950 g

Accessories

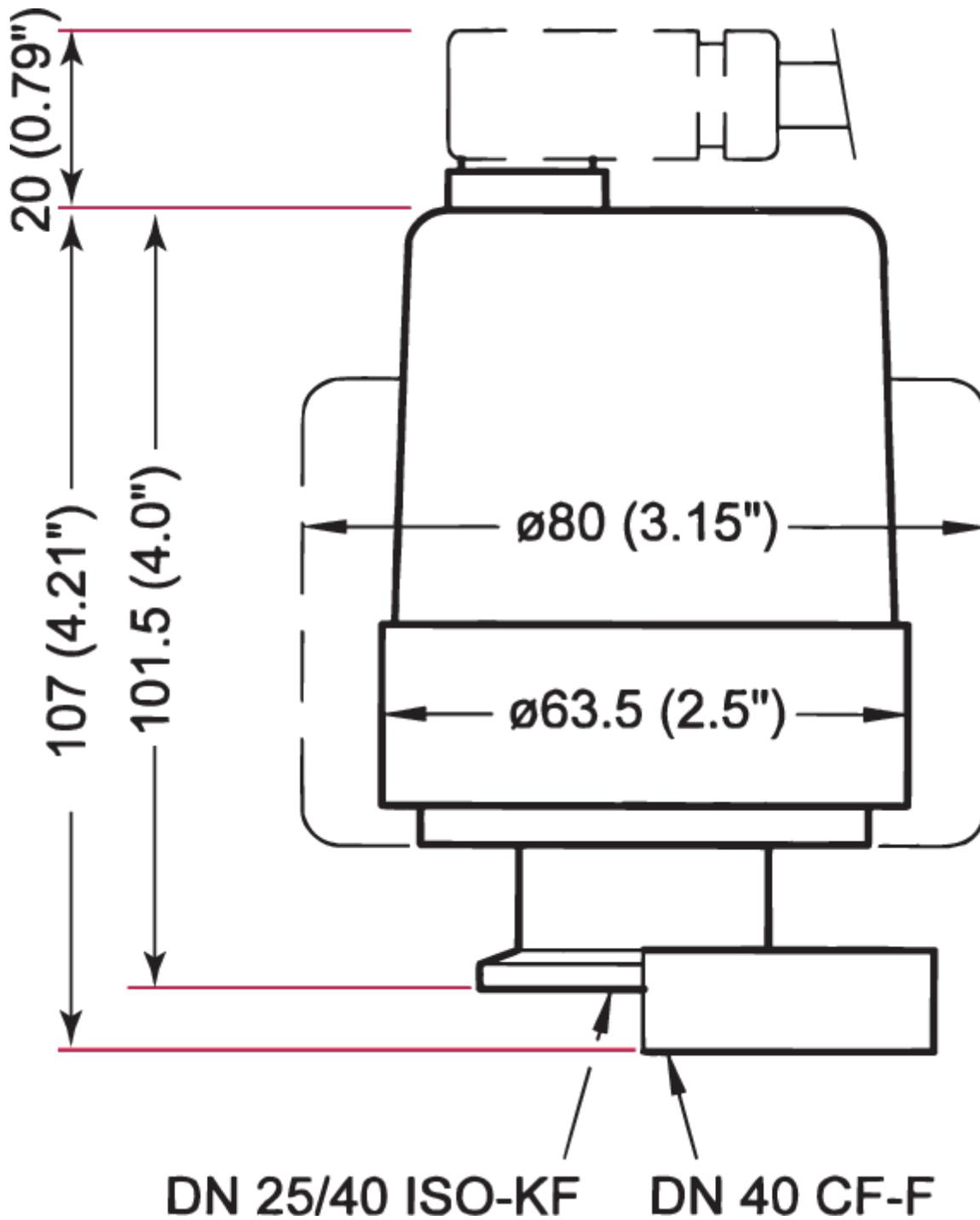
Accessory

Mating connector (B 4707 283 MA)

Measurement cable

Sensor cable, 3 m (PT 448 250 -T)

Dimensions



Your local contact

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2 Solder the connection cable according to the diagram.

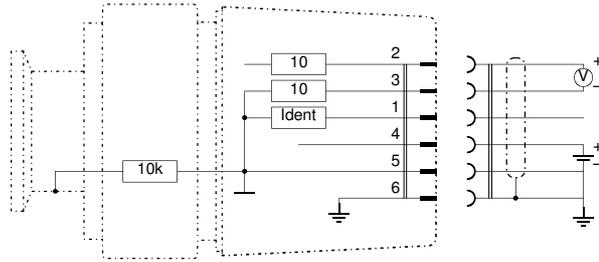
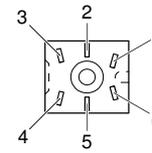


Figure 1: Electrical connection

- Pin 1 identification
- Pin 2 signal output (measuring signal)
- Pin 3 signal common
- Pin 4 supply
- Pin 5 supply common
- Pin 6 screen



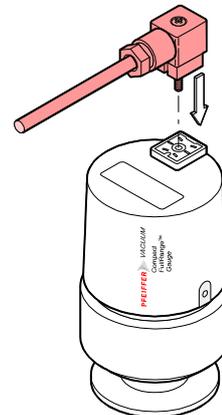
Connector, soldering side

WARNING

The supply common (pin 5) and the screen (pin 6) must be connected to the supply unit with protective ground. Incorrect connection, incorrect polarity, or inadmissible supply voltages can damage the gauge.

3 Reassemble the connector.

4 Plug in the connector.
Secure the connector on the gauge with the screw (tightening torque ≤ 0.2 Nm).



4 Operation

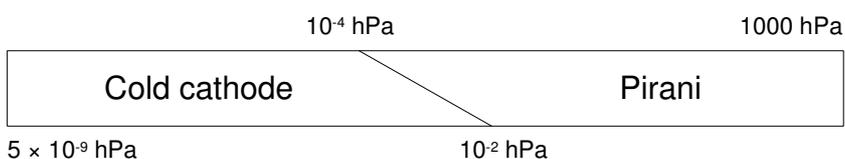
As soon as the required voltage is applied, the measuring signal is available between pins 2 and 3. (→ Appendix B for the relationship between the measuring signal and the pressure).

Allow for a stabilizing time of approx. 10 min. Once the gauge has been switched on, permanently leave it on irrespective of the pressure.

4.1 Measurement Principle, Measuring Behavior

The PKR 251 consists of two separate measurement systems (Pirani and cold cathode system according to the inverted magnetron principle). They are combined in such a way that for the user, they behave as one single measurement system.

The optimum measurement configuration for the particular pressure range, in which measurement is performed, is used:



- The Pirani measurement circuit is always on.
- The cold cathode measurement circuit is controlled by the Pirani circuit and is activated only at pressures $< 1 \times 10^{-2}$ hPa.

The identification output (pin 1) indicates the current status of the gauge:

Pressure	Green lamp on the gauge	Operating mode	Identification
$p > 1 \times 10^{-2}$ hPa		Pirani-only mode	11.1 kΩ (Pirani)
$p < 1 \times 10^{-2}$ hPa		Pirani-only mode (cold cathode measurement circuit not ignited)	11.1 kΩ (Pirani)
		Combined operation	9.1 kΩ (combined)

As long as the cold cathode measurement circuit has not ignited, the measurement value of the Pirani is output as measuring signal (if $p < 5 \times 10^{-4}$ hPa, "Pirani underrange" is displayed).

Gas type dependence

The measuring signal depends on the type of gas being measured. The curves are accurate for N₂, O₂, dry air and CO. They can be mathematically converted for other gases (→ Appendix C).

If you are using a Pfeiffer Vacuum measurement unit for Compact Gauges, you can enter a calibration factor to correct the measurement value displayed (→  of that measurement unit).

Ignition delay

An ignition delay occurs when cold cathode gauges are switched on. The delay time increases at low pressures and for clean, degassed gauges it is typically:

- 10^{-5} hPa ≈ 1 second
- 10^{-7} hPa ≈ 20 seconds
- 5×10^{-9} hPa ≈ 2 minutes

The ignition is a statistical process. Already a small amount of depositions on the inner surfaces can have a strong influence on it.

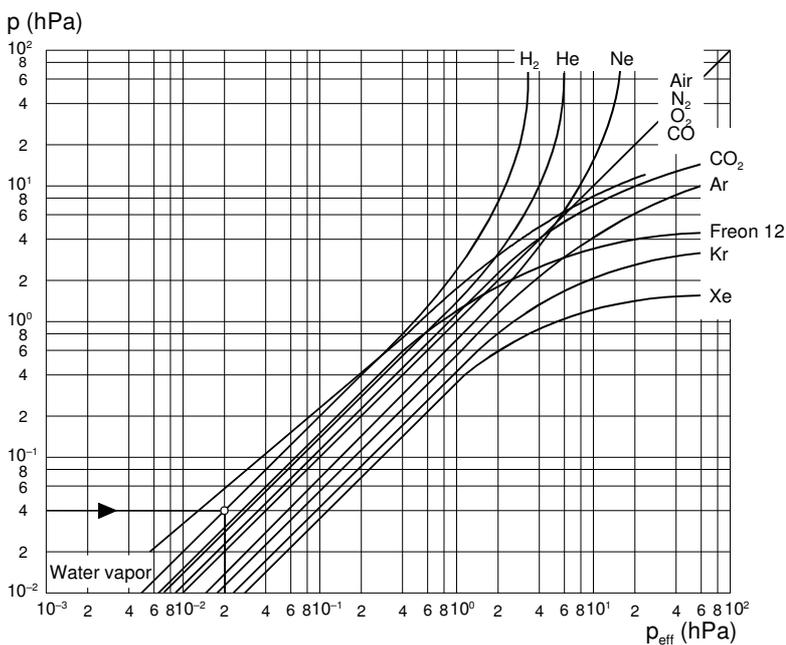
Conversion table

Measuring signal U [V]	[hPa]	Pressure p [Torr]	[Pa]
< 0.5		Sensor error	
0.5 ... 1.82		Underrange	
1.82	5.0×10^{-9}	3.8×10^{-9}	5.0×10^{-7}
2.0	1.0×10^{-8}	7.5×10^{-9}	1.0×10^{-6}
2.6	1.0×10^{-7}	7.5×10^{-8}	1.0×10^{-5}
3.2	1.0×10^{-6}	7.5×10^{-7}	1.0×10^{-4}
3.8	1.0×10^{-5}	7.5×10^{-6}	1.0×10^{-3}
4.4	1.0×10^{-4}	7.5×10^{-5}	1.0×10^{-2}
5.0	1.0×10^{-3}	7.5×10^{-4}	0.1
5.6	1.0×10^{-2}	7.5×10^{-3}	1.0
6.2	0.1	7.5×10^{-4}	10
6.8	1.0	0.75	100
7.4	10	7.5	1000
8.0	100	75	1.0×10^4
8.6	1000	750	1.0×10^5
8.6 ... 9.5		Overrange	
9.5 ... 10.5		Sensor error (Pirani defective)	

C: Gas Type Dependence

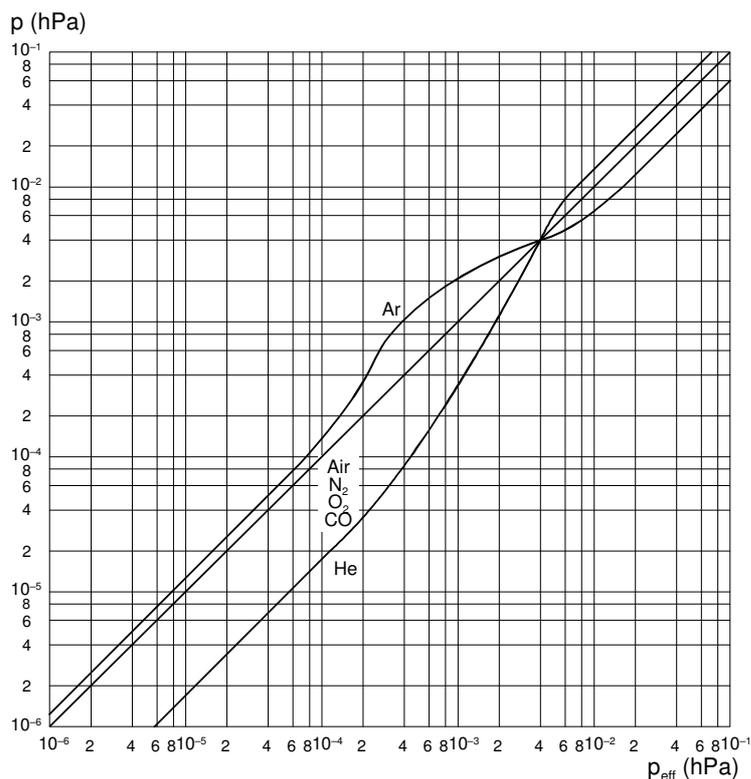
Indication range above 10^{-2} hPa (Pirani only mode)

Pressure indicated (gauge calibrated for air)



Indication range 10^{-6} ... 0.1 hPa

Pressure indicated (gauge calibrated for air)



Indication range below 4×10^{-5} hPa

In the range below 10^{-5} hPa, the pressure indication is linear. For gases other than air, the pressure can be determined by means of a simple conversion formula:

$$p_{\text{eff}} = K \times \text{pressure indicated}$$

where	gas type	K
	air (N ₂ , O ₂ , CO)	1.0
	Xe	0.4
	Kr	0.5
	Ar	0.8
	H ₂	2.4
	Ne	4.1
	He	5.9

These conversion factors are average values.



Caution



A mixture of gases and vapors is often involved. In this case, accurate determination is only possible with a partial pressure measurement instrument, e.g. a quadrupole mass spectrometer.

THE PIRANI GAUGE FOR THE MEASUREMENT
OF SMALL CHANGES OF PRESSURE

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(Received March 20, 1931)

ABSTRACT

The application of the Pirani gauge to the measurement of small pressure changes is discussed. Both nickel and tungsten wires are used as filaments in the gauge. Nickel wire not only has the greater sensitivity but possesses several other advantages. The theory of the gauge is developed so that it is possible to predict the effect of change in length or diameter of the wire upon the sensitivity of the gauge. The theory also predicts that there is an optimum temperature to which the wire should be heated for maximum sensitivity of the gauge. The observed and computed values of the optimum temperature are compared. In some cases the agreement is as good as can be expected and in the others the discrepancy is easily explained. The maximum sensitivity attained is a galvanometer deflection of 1 mm for a pressure change of air equivalent to 5×10^{-9} mm of mercury.

INTRODUCTION

THE possibility of using the variation in heat conductivity of a gas with pressure as a measure of low pressures was first suggested by Pirani.¹ Recent experimenters^{2,3} have shown that such a gauge is capable of responding to very small changes in pressure.

These investigators have been primarily interested in a gauge which will determine the actual pressure existing in a chamber after it has been calibrated by comparison with an absolute gauge such as the McLeod. The aim of this experiment is to develop a gauge with a high sensitivity to very small pressure changes.

THEORY

It is easily shown that the quantity of heat Q conducted by a gas when the mean free path is large compared to the dimensions of the container is

$$Q = nGA tH/6N \quad (1)$$

where n is the number of molecules per cm^3 , G the mean molecular velocity, A the area of the heated element, t the temperature difference between the heated element and its surroundings, H the molecular heat at constant volume, and N the number of molecules per gram molecule. Experimental measurements give a value of the heat transfer which is usually less than that predicted by this equation. This is because the molecules striking the heated wire do not attain temperature equilibrium with it. The ratio of the actual amount of heat conducted from the heated element to that computed by

¹ M. Pirani, *Verh. d. Deutsch. Phys. Ges.* **8**, 24, 686 (1906).

² A. M. Skellet, *J. O. S. A. and R. S. I.* **15**, 56 (1927).

³ L. F. Stanly, *Phys. Soc. Proc.* **41**, 194 (1929).

Eq. (1) is known as the accommodation coefficient and has been measured for some gases. Soddy and Berry⁴ give the values of the actual amount of heat conducted and the values of the accommodation coefficient for gases striking a heated tungsten surface. The values of the accommodation coefficient range from 0.25 in the case of hydrogen to 1.0 in the case of argon and neon. The values of the actual amount of heat conducted by various gases deviate by less than 10 percent from a mean value for a number of the common gases. Hence we may expect that the sensitivity of the Pirani gauge will be nearly the same for this group of gases.

In the application of the above principle to the measurement of pressure changes the temperature change in the wire resulting from a change in the heat conductivity of the gas is usually measured by the change in resistance. This resistance change is in turn measured by a Wheatstone bridge. If the pressure change to be measured is not large the galvanometer deflection is the most accurate method of determining the magnitude of the change.

The bridge potential serves as a source of power to heat the wire. The energy dissipated by a heated wire must be equal to that supplied, hence neglecting conduction to the leads

$$\frac{E^2}{R} = A\gamma(T^4 - T_0^4) + A\alpha p(T - T_0) \quad (2)$$

where E is the potential across the ends of the wire, R the resistance and A the area of the wire, T and T_0 the temperature of the wire and of its surroundings, respectively, p the pressure of the gas and γ and α constants. Since the resistance change corresponding to the pressure changes normally measured is small we may assume that the power supplied to the wire is constant. Then by differentiation of (2),

$$\frac{dT}{dp} = - \frac{\alpha(T - T_0)}{4\gamma T^3 + \alpha p}.$$

At low pressures the amount of heat dissipated from the wire by radiation is large compared to that conducted by gas hence we may neglect αp in comparison to $4\gamma T^3$. Then

$$\frac{dT}{dp} = K \frac{T - T_0}{T^3} \quad (3)$$

where K is a constant.

Obviously there is a relation between T and T_0 for which the temperature change of the wire will be a maximum for a given pressure change. This relation is given by

$$\frac{d}{dT} \left[\frac{(T - T_0)}{T^3} \right] = 0$$

or

$$T = 3T_0/2.$$

⁴ F. Soddy and A. Berry, Proc. Roy. Soc. **83**, 254 (1910).

Substituting this value in (3) we obtain,

$$\left[\frac{dT}{dp} \right]_{\max} = \frac{K'}{T_0^2}. \quad (4)$$

Hence the value of the maximum temperature change of the wire for a given pressure change is inversely proportional to the square of the absolute temperature of the surroundings of the wire.

Since the temperature change resulting from a given pressure change is normally small we may assume that

$$R = R_0[1 + \alpha(T - 273)]$$

or

$$dR = R_0\alpha dT.$$

Substituting this value of dT in (3) we obtain,

$$\frac{dR}{dp} = K''R_0 \frac{T - T_0}{T^3}. \quad (5)$$

Obviously dR/dp has the same maximum as dT/dp . The maximum galvanometer deflection does not necessarily correspond to the maximum resistance change, however.

The current through the galvanometer in a Wheatstone bridge circuit is given by

$$I_g = \frac{EdR}{4RR_g + 4R^2}$$

if the battery resistance is small and the four arms of the bridge are approximately equal. Substituting for dR from (5),

$$I_g = K''' \frac{R_0E}{RR_g + R^2} \frac{T - T_0}{T^3} dp. \quad (6)$$

Obviously the galvanometer deflection may be increased by increasing the potential of the bridge. This factor is limited, however, because the wire must be heated to its optimum temperature.

The relation between the potential drop across the wire and the temperature may be obtained from (2). In general the heat conducted by the gas may be neglected in comparison to that dissipated by radiation and T_0^4 in comparison to T^4 . Hence

$$E = (\gamma AR)^{1/2} T^2.$$

Substituting this value of E in (6)

$$I_g = K \frac{R_0(AR)^{1/2} \cdot T - T_0}{RR_g + R^2} \frac{1}{T} dp. \quad (7)$$

The optimum temperature of the gauge wire for maximum galvanometer deflection may be determined from (7). In the general case this solution is difficult but several special cases which are of interest may be treated.

If we assume that the galvanometer resistance is large compared to the resistance of the arms of the bridge, (7) reduces to

$$I_g = K' \frac{T - T_0}{R^{1/2} T} d\phi.$$

But

$$R = R_0 [1 + \alpha(T - 273) + \beta(T - 273)^2]$$

where the terms of second order must be included if the action of the gauge is to be described over any considerable range. Hence

$$I_g = \frac{K'''(T - T_0)}{[1 + \alpha(T - 273) + \beta(T - 273)^2]^{1/2} T} d\phi.$$

The optimum temperature of the wire may be determined by

$$\frac{d}{dT} \left[\log \frac{T - T_0}{[1 + \alpha(T - 273) + \beta(T - 273)^2]^{1/2} T} \right] = 0$$

or

$$2\beta T^3 + (\alpha - 546\beta - 4\beta T_0)T^2 - T_0(3\alpha - 1638\beta)T - 2T_0[1 - 273\alpha + (273)^2\beta] = 0. \quad (8)$$

If the galvanometer resistance is small as compared to the resistance in the bridge arms Eq. (7) reduces to

$$I_g = K^* \frac{T - T_0}{R^{3/2} T}$$

and the value of T for maximum I_g is given by

$$6\beta T^3 + (3\alpha - 1638\beta - 8\beta T_0)T^2 - 5T_0(\alpha - 546\beta)T - 2T_0[1 - 273\alpha + (273)^2\beta] = 0. \quad (9)$$

RESULTS

The experimental arrangement used in obtaining the results given below is shown in Fig. 1. The leak was controlled by a stopcock so that it could be opened or closed as desired. This gave a constant pressure change and the corresponding galvanometer deflection could be observed for various bridge potentials and various samples of wire.

The gauge formed one arm of a Wheatstone bridge. The other arms consisted of resistances variable in small steps so that the arms of the bridge could be kept approximately equal. The galvanometer used has a resistance of 17 ohms and a sensitivity of 11.6 mm per microvolt. Resistance was connected in series or parallel with it to obtain the high and low galvanometer resistances used.

Equation (7) shows that the galvanometer deflection should be directly proportional to the pressure change. This was verified beyond the limits of the McLeod gauge by connecting a small leak to a pump through a stopcock. This leak was adjusted to give several cm deflection of the galvanometer as

it was turned on or off. As the pressure in the gauge was increased by the use of another leak the deflection produced by opening or closing the first leak remained constant.

Equation (7) also shows that the sensitivity of the gauge is proportional to the square root of the area of the wire. It is possible to multiply the sensitivity of a nickel wire gauge by two or three merely by flattening the wire.

The effect of the length of the gauge wire upon the sensitivity may be determined from (7). Since A , R , and R_0 are all proportional to the length of the wire it is evident that the sensitivity will be directly proportional to

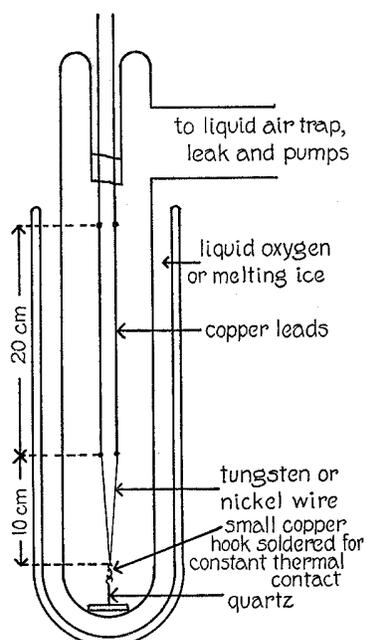


Fig. 1. Construction of the Pirani gauge.

the length of the wire if the galvanometer resistance is large compared to the resistance of the bridge arms. On the other hand, if the galvanometer re-

TABLE I.

Galvanometer resistance	Length of wire (cm)	Maximum deflection
312	20	22.4
	10	12.0
	5	6.3
17	20	23.0
	10	20.1
	5	15.9
3.86	20	24.5
	10	24.8
	5	23.2

sistance is small the sensitivity is independent of the length of the wire. Table I shows the effect of the length of the wire upon the sensitivity of the gauge. In each case the gauge was constructed of nickel wire 0.001 inch in diameter and the walls of the gauge were maintained at the temperature of melting ice.

The variation of the sensitivity of the gauge with diameter of the wire may also be predicted. If the galvanometer resistance is large compared to the resistance of the gauge, the diameter of the wire should be decreased and if the galvanometer resistance is low the diameter of the wire should be increased. Hence for maximum sensitivity the wire should be as long as convenient and the diameter should be adjusted so that its resistance is of the

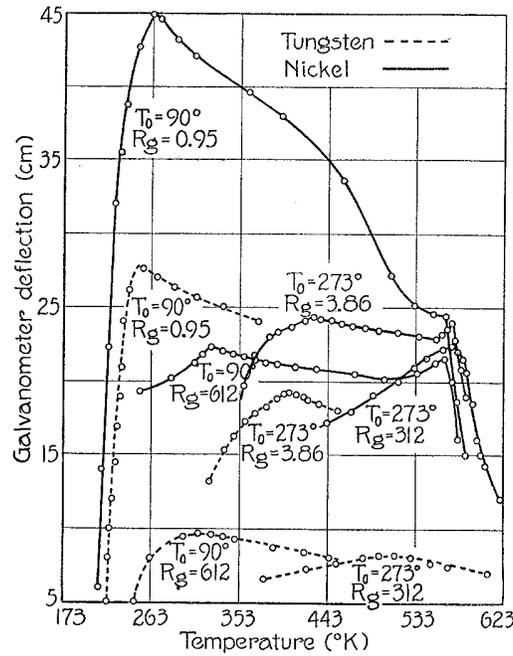


Fig. 2. Curves showing the relation between the temperature of the gauge wire and the sensitivity of the gauge. T_0 is the temperature of the walls of the gauge and R_g the galvanometer resistance.

same order of magnitude as the galvanometer resistance. In general a galvanometer with low resistance is preferable since the corresponding lower resistance in the bridge arms permits the use of lower battery potential which decreases the tendency of the galvanometer to drift.

The relation between the sensitivity of the gauge and the temperature of the wire is shown in Fig. 2. The tungsten and nickel wires used in obtaining these curves were 20 cm long and 0.001 inch in diameter. The temperature was determined by the known relation between the temperature and resistance. For tungsten the values $\alpha = 5.24 \times 10^{-3}$ and $\beta = 0.7 \times 10^{-6}$ were used in the well-known resistance formula. The temperature of the nickel wire

was read from the curve shown in Fig. 3 which was determined for the wire used in this experiment.

It will be noted that all the temperature sensitivity curves for nickel wire (Fig. 2) have either a primary or a secondary maximum at approximately 570° after which the sensitivity decreases very rapidly. This is obviously due to the rapid increase in the slope of the temperature resistance curve and the sudden break at 615° . The observed temperature at which this break occurs should be less when the wire is used as a gauge because the ends of the gauge wire are cooled by conduction of heat to the leads. This view is substantiated by the fact that the apparent temperature at which the maximum occurs decreases when a shorter wire is used.

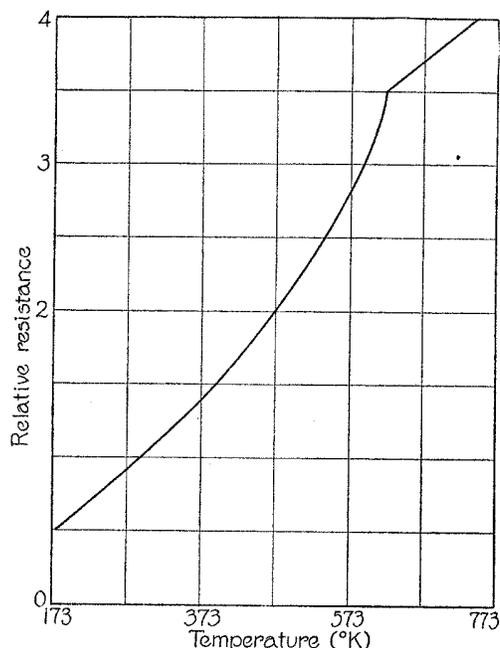


Fig. 3. Temperature resistance curve for nickel wire.

In Table II, T_0 is the temperature of the gauge walls, R_0 is the galvanometer resistance, R is the resistance of the wire at its optimum temperature, E is the bridge potential necessary to produce this temperature, $T(\text{obs.})$ and D the optimum temperature and the galvanometer deflection at that temperature, respectively, as determined from Fig. 2, and $T(\text{comp.})$ the optimum temperature computed from Eqs. (8) and (9). In obtaining the values of $T(\text{comp.})$ the proper equation is chosen depending upon the value of the galvanometer resistance, and the values of T_0 , α , and β are substituted after which the equation may be solved for T . For tungsten the values of α and β previously given were used and for nickel the same constants were determined from Fig. 3 to fit the curve approximately in the region in which the observed temperature was known to lie. It will be noted that the computed

temperatures when $T_0=90^\circ$ are much lower than the observed. This is partially due to heat conduction along the leads and partially to the decrease in the constant γ appearing in Eq. (2) or, in other words, a decrease in the efficiency of radiation at low temperatures. In fact with a potential of only 0.0003 volt applied to the bridge the lowest temperature attained by the nickel filament was 209° and by the tungsten 213° .

The secondary maxima in the temperature sensitivity curves of nickel wire are not predicted by the equations but they probably would be if the variation in slope of the temperature resistance curve were taken into account and the equation of the curve were expressed more accurately.

TABLE II

	T_0	R_g	R	E	T Comp.	T Obs.	D
Nickel	90	612	41.9	0.5	248	313	22.3
	90	0.95	30.6	0.3	136	261	45.0
	273	312	99.0	2.9	533	563	22.4
	273	3.86	61.8	1.1	429	393	24.5
Tungsten	90	612	23.3	0.5	195	311	9.6
	90	0.95	17.0	0.4	120	254	27.6
	273	312	46.5	3.0	715	513	8.2
	273	3.86	33.5	1.3	415	401	19.3

* All temperatures given on the Kelvin scale.

Table II shows that the sensitivity attained by the use of nickel wire is in all cases greater than that for tungsten. Nickel wire has the additional advantage that it may be flattened more easily than tungsten which greatly increases the sensitivity as the previous discussion has shown. Tungsten wire has the disadvantage that the slightest vibration will cause its resistance to change sufficiently to keep the galvanometer moving back and forth over several cm.

Immersing the walls of the gauge in liquid oxygen approximately multiplies the sensitivity of the gauge by two when the galvanometer resistance is high and by seven when the galvanometer resistance is low. This difference in the sensitivity ratio is to be expected for Table II shows that the resistance of the bridge arms at optimum temperature is much lower when $T_0=90^\circ$ than when $T_0=273^\circ$. Equation (7) and the preceding discussion show that this decrease in resistance will decrease the sensitivity when the galvanometer resistance is high but not when the galvanometer resistance is low.

Many factors enter into the computation of the relative sensitivity of the gauge when the walls are at the temperature of melting ice and at the temperature of liquid oxygen. For example the relation between the pressure and the heat conductivity of the gas will change both because more molecules must be present at liquid oxygen temperatures to exert a given pressure and because the mean molecular velocity is smaller. Also, as previously suggested, the radiation constant (γ in Eq. (2)) probably decreases at the lower temperature and it is reasonable to expect that the value of the accommodation coefficient depends upon the temperature. The effect of heat conduction

from the filament to the leads upon the sensitivity of the gauge has been neglected so that it is impossible to predict the change in sensitivity which will result from the reversal in the direction of this flow. Such a reversal actually occurs in some cases for when the walls of the gauge are immersed in liquid oxygen the temperature of the filament is less than the temperature of the leads. Due to the impossibility of computing the magnitude of the latter effect and the difficulty in computing some of those previously given no attempt is made to predict the increase in sensitivity when the walls of the gauge are reduced to the temperature of liquid oxygen.

Reducing the walls of the gauge to the temperature of liquid oxygen makes the reaction of the gauge very slow. For example with the gauges at the temperature of melting ice the galvanometer would reach equilibrium about 10 seconds after the stopcock was closed. At liquid oxygen temperature the time required to attain equilibrium was often several minutes. This time lag may be accounted for to some extent by the fact that there must be three times as many molecules in the gauge and their velocity must be much slower when the walls of the gauge are at the temperature of liquid oxygen so that it should take longer for the gauge to pump out. This factor cannot, however, account for the great difference observed in the time lag in the two cases and neither can it account for the observed fact that the time lag of the gauge decreases rapidly with an increase in temperature of the filament since the area of the filament is so small in comparison to the area of the walls that it can have no appreciable effect upon the mean velocity of the molecules. The observed dependence of the time lag upon the temperature of the wire suggests that it may to some extent be due to the adsorption of a layer of gas by the filament.

It is possible to obtain a galvanometer deflection of 1 mm for a pressure change of air equivalent to $5 \pm 1 \times 10^{-9}$ mm of mercury by forming the gauge from a well-flattened piece of nickel wire 25 cm long and originally 0.0015 inch in diameter and using the galvanometer specified above at maximum sensitivity.

Under similar conditions the sensitivity of the gauge for hydrogen is $4 \pm 1 \times 10^{-9}$ mm of mercury per mm galvanometer deflection.

The sensitivity and characteristics of different gauges will vary due to variations in the original size and the degree of flatness of the wire.

CONCLUSION

In order to measure pressure changes of less than 10^{-7} mm of mercury it is obvious that the zero position of the galvanometer must be steady. If the ordinary precautions necessary in connecting a Wheatstone bridge of high sensitivity are observed, if the bridge potential is constant, and if the walls of the gauge are maintained at a constant temperature such as melting ice or liquid oxygen, the zero drift of the gauge becomes negligible provided that the pressure changes take place over a short period of time.

The operation of the gauge is not satisfactory when the walls are exposed to the variations of room temperature. A compensating gauge greatly im-

proves the stability of the system but is not as satisfactory as one gauge immersed in a constant temperature bath.

The stability of the gauge may be improved by keeping the bridge potential low. This may be accomplished by proper choice of the galvanometer as previously described and by operating the gauge below its optimum temperature. The extent to which the temperature should be reduced below its optimum value depends upon the difficulty arising from zero drift and upon the rate at which the sensitivity decreases with decrease in temperature. In some cases it is possible to reduce the bridge sensitivity to one half* of its value at the optimum temperature while the gauge sensitivity is reduced only 15 percent. In such cases the decrease in bridge potential would probably be an advantage.

* That is $\Delta R/R$ for unit galvanometer deflection is doubled.

COLD CATHODE IONISATION GAUGES

for the measurement of low pressures

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Summary

COLD CATHODE IONISATION GAUGES in which the discharge is maintained in an axial magnetic field provide a convenient and rapid means of measuring pressure in the range 10^{-2} to 10^{-7} mm. Hg. These instruments are simple to make and operate and it is virtually impossible to damage them. With such a gauge, measurement of pressure is effected by a robust pivot-meter which measures a current of ions formed by electron bombardment. Primary electrons are released by cold emission from a pair of cathodes and many secondary electrons are generated by the ions themselves. The magnetic field causes the electrons to move in tight spirals to and fro between the two cathode plates. In this way the number of ions per electron, between initial emission and eventual escape from the discharge to the anode, is much increased. A review is given of the construction, characteristics and performance of various types of cold cathode gauge. The influence is reported of size and shape of the electrodes, of applied voltage, of magnetic field and of the nature of the gas. Reference is made to the performance at relatively high pressures (10^{-2} to 10^{-3} mm. Hg). Attention is drawn to the generation of radio frequencies by cold cathode gauges.

Sommaire

LE MANOMETRE A IONISATION A cathode froide, dans lequel la décharge est maintenue dans un champ magnétique axial, est un moyen pratique et rapide de mesurer des pressions entre 10^{-2} et 10^{-7} mm. Hg. Ces instruments sont simples à construire et on peut presque jamais les endommager. Avec une telle jauge la lecture se fait sur un instrument à pivot, robuste, qui mesure le courant ionique formé par bombardement électronique. Des électrons primaires sont libérés par émission froide au départ d'une paire de cathodes, et de nombreux électrons secondaires sont générés par les ions eux-mêmes. Le champ magnétique oblige les électrons à se mouvoir en une spirale serrée de et vers les plaques cathodiques. De cette façon le nombre d'ions par électron, entre l'émission initiale et l'échappement final vers l'anode, est fortement augmenté. L'on passe en revue la construction, les caractéristiques et performances de différents types de jauges à cathode froide. Les auteurs rendent compte de l'influence de la forme et des dimensions des électrodes, de la tension appliquée du champ magnétique et de la nature du gaz. Ils se réfèrent à la performance sous pressions relativement élevées (10^{-2} à 10^{-3} mm. Hg). Ils attirent l'attention sur la génération de fréquences radio par des jauges à cathode froide.

INTRODUCTION

VACUUM GAUGES which operate electrically have several attractive features compared with other gauges, not the least of which is that they can conveniently be controlled from a distance; they are easily degassed and are not a source of contamination. In 'ionisation gauges', suitable for the measurement of pressures less than 10^{-3} mm. Hg, the ion current, established by an appropriate voltage, is used as a measure of pressure. Electrons, X-rays and alpha-

particles have all been used to ionise the residual gas.

In the earliest and simplest ionisation gauges, as developed by Dushman and Found¹ and Misamichi So², electrons are supplied by thermionic emission and the relatively large electron currents are of the order of several milliamperes. The pressure is indicated by the positive ion current, of the order of a microampere or less, flowing to an electrode maintained at a potential which is negative with respect to the cathode. A hot cathode is easily damaged by electrical or mechanical mishandling and is easily poisoned; failure of the vacuum may destroy

*M.S. received December, 1953.

COLD CATHODE IONISATION GAUGES

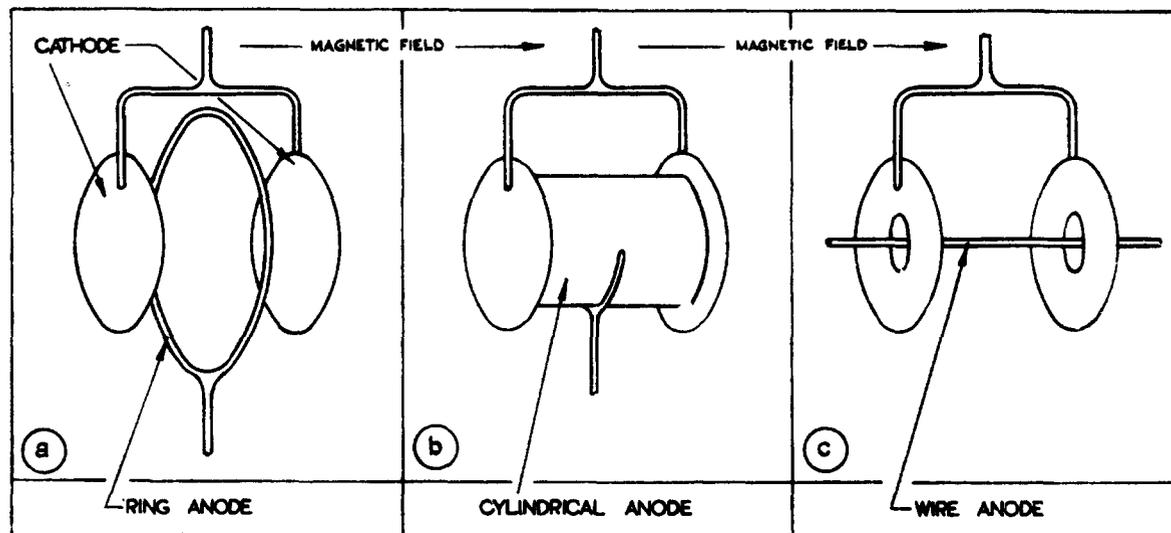


Fig. 1. Possible arrangements of electrodes. F. M. Penning.⁴

the filament. The gauge must therefore be accessible and so fitted to the system that the cathode can be replaced simply and rapidly.

These disadvantages are not present in cold cathode gauges. The primary electron current, drawn from the cathode by cold emission under a relatively high electrostatic field, is small. The gauge must therefore be designed so that each electron has a much greater chance of ionising a gas molecule than in a thermionic gauge. This is achieved in two ways, by applying an axial magnetic field which causes the electrons to travel in spiral tracks and by employing two cathode discs between which the electrons move to and fro. Various arrangements of the electrodes are illustrated in Fig. 1. The ion currents are relatively large and are measured by robust, pivoted meters.

The present purpose is to review the performance of cold cathode gauges since they appear to be less popular than their great practical value warrants. Such gauges may be used to give a direct indication of pressure over the range 10^{-2} mm. Hg to 10^{-7} mm. Hg. They are simpler and easier to construct than thermionic gauges, are practically indestructible and unaffected by application of the high voltage even at

atmospheric pressure. However, sputtering may cause electrical leakage if steps are not taken to mask the leads and the discharge causes some decomposition of oil vapour. It is advisable to clean the electrodes occasionally. If the pressure is too low the arc will not strike so that the lowest practical pressure at which the gauge may be used is somewhat larger than this critical pressure. Means of overcoming this are discussed in the text.

Certain workers view all ionisation gauges with suspicion. The objection is based on the consideration that an ion current necessarily removes gas from the system so that the behaviour of the gauge must necessarily be associated with a pumping action. The argument concludes that the pressure recorded by the gauge is lower than that which exists in the system. Without examining methods used in calibrating, two points may be made. In a system of small volume the gauge is an integral part of the system, the pumping action assists evacuation and the 'effective pressure' in the gauge is that of the system. The criticism may be valid in the case of a large volume if the gauge operates at the end of a side tube and not directly in the pump line. Errors occur with any gauge under these circumstances¹⁸. The

relevant pressure can only be recorded, whatever gauge is used, if it is placed directly in the enclosure studied or in the pumping line close to the vessel. If this is done the action of the gauge assists the pumps. If the geometric arrangement is poor an ionisation gauge may be misleading; so will any other gauge.

THE COLD CATHODE GAUGE OF PENNING

The usual means of increasing the effective path of an electron between the cathode and the anode, by applying a magnetic field, was first used in 1934 by Gaede³ in a thermionic gauge; it was also used in 1937 by Penning⁴ in his first cold cathode gauge. Two cathode plates and a single anode are so arranged that it is possible for the electrons to oscillate to and fro between the cathodes. The arrangement is illustrated in Fig. 1(a). The magnetic field is applied parallel to the axis to prevent the electrons moving directly from the cathode to the anode; they move in tight spirals between the two negative electrodes. An electron moving with a total energy of even 2 kV in a field of 1,000 oersted moves in a spiral, the radius of which is a fraction of a millimetre.

Stability of the discharge is achieved by using a large series resistor. This resistor plays an important part. If for any reason the current through the gauge falls, the effective resistance of the gauge increases and consequently the voltage across the discharge increases. The current then rises because of the increase in voltage and to some extent the discharge is self-stabilising. The 'ballast resistor' also prevents the flow of excessive currents.

Different modes of oscillation may take place between the cathodes. This is revealed by sudden small changes in the current which are accompanied by changes in shape of the glow between the electrodes. Below a certain pressure, characteristic of a particular gauge, the glow discharge ceases and the current falls to zero. At pressures just above this critical or 'cut-off' pressure the discharge is not immediately established when the voltage is applied. Once the discharge strikes, it continues so long as the

pressure remains above the critical value. There is, similarly, a critical or 'cut-off' voltage and a critical or 'cut-off' magnetic field. If one of the three parameters, pressure, voltage or magnetic field, is reduced, the current falls to a very small but finite value; further reduction causes the discharge to cease altogether.

These phenomena are closely related. The small primary flow of electrons generated by cold emission is much enhanced by secondary electrons released in the process of ionisation and by ionic bombardment of the cathodes. The glow discharge at any given pressure resembles that at much higher pressures with no magnetic field. The generation of ions by the collision of ions with gas molecules is not large⁵; most ions are formed by the collision of electrons with molecules. The most important influence of the ions, with a small ratio of charge to mass, is to reduce the effective space charge between the electrodes and so to modify the field distribution. Even with applied voltages of several kilovolts the field within the discharge is small⁶. At low pressures the number of primary electrons from cold emission is virtually independent of gas pressure; the number of secondaries, arising from ionic bombardment is directly controlled by the gas pressure. It follows that the variation in the ion current with pressure is largely determined by the emission of secondary electrons.

The arrangement of the magnetic field and of the electrodes is designed to ensure that the path of the electrons is long so that once an electron is released in the discharge it shall produce many ions before escaping to the anode. A high concentration of electrons in the discharge is a necessary condition for a large ion current and the importance of the release or escape of electrons to the anode lies in its influence on this concentration. If no electrons escaped, clearly a cascade process would be set up until the current was limited only by the ballast resistor and was independent of pressure. In practice, the cascade builds up until an equilibrium is established. Maintenance of the discharge is determined by the rate at which electrons, and therefore ions, are released at any instant by the electrons already present. The

observed influence on the ion current of such parameters as the field strength arises in this way. If electrons are free to pass directly to the anode, that is to 'escape', the probability of ionisation is low and the sensitivity is poor. As the pressure is reduced there comes a stage when the rate of production of secondaries is no longer adequate to compensate for the rate at which electrons escape. Immediately this stage is reached the 'cascade' decays and the current falls to a very low value which must be of the order of the current carried by the primary electrons and their associated ions. Since this current is very small, it is clear that the discharge current is, in effect, a measure of the pressure.

Reduction of the magnetic field or the electric field increases escape of electrons; hence it is clear that there is a critical magnetic field and a critical voltage. In the case of the latter there is also a direct effect on the primary electron current. It should be noted that although the field distribution in the case illustrated in Fig. 1(a) discourages escape of electrons, the sensitivity is improved with a cylindrical anode, Fig. 1(b), *i.e.*, fewer electrons escape, but the improvement is limited. If the pressure, voltage or magnetic field be reduced below the critical level so that the discharge ceases, and is then raised just above this 'cut-off', the discharge may not strike since the initial supply of ions and consequently of secondary electrons may be insufficient. Increase in the background ionisation by a radioactive contaminant on the electrodes, by a sharp point on one of the cathodes or by a 'starter' filament may be large enough to ensure reliable and reproducible striking of the discharge. Such techniques have a marked influence on the regularity with which the gauge strikes, they have little bearing on the sensitivity.

Once the discharge is established, the primary current is not important. The rate of escape of electrons depends only on the electric and magnetic fields and the geometrical arrangement of the electrodes. It is confirmed by reports^{7,8} and borne out by our experience that the materials used in the construction have little influence on the performance during the discharge. It has been shown⁹ that the rate at which electrons escape exceeds that which

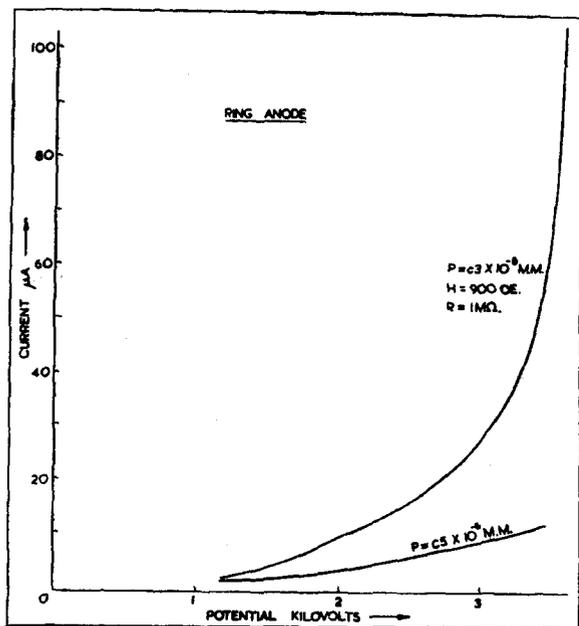
can be explained by simple collision of electrons with gas molecules. Random, transient electric fields present in the discharge lead to oscillations of the electron-ion plasma in the arc. The fields associated with such oscillations are responsible for moving electrons across the magnetic field. These oscillations are an essential feature of discharges in a magnetic field and may be detected by probes or coils.

In the following sections many of the practical features and the performance of these gauges are discussed and these general comments are illustrated in detail.

GEOMETRY AND ARRANGEMENT OF THE ELECTRODES

There are several possible systems of electrodes suggested by the requirements outlined in the previous section. The three arrangements proposed by Penning⁴ are shown in Fig. 1 of which Fig. 1(a) illustrates the earliest form of gauge used. In this, the magnetic field was supplied by a permanent magnet, the cathodes were small rectangular or circular metal plates and the anode was a ring of wire. It has been suggested⁸ that if the cathodes be extended until they 'overlap' the anode, the effect of slight variations of the magnetic field is reduced. In some of the commercial variants this has been elaborated by having cathodes in the form of a metal box surrounding the ring anode. The precise dimensions of the electrodes are not of great importance; the larger the electrodes, the larger the ion current. The ion current depends on the volume available for ionisation; it is roughly proportional to the distance between the cathodes. It is also roughly proportional to the diameter of the anode ring. A typical gauge of this form would have circular cathodes about $1\frac{1}{2}$ inch. in diameter, 1 inch apart, and an anode-ring of 1 inch diameter.

A modification in which the ring anode was replaced by a metal cylinder of similar diameter was suggested by Penning and Nienhuis¹⁰ and also by Hayashi and his co-workers¹¹; it is illustrated in Fig. 1(b). The metal cylinder extends almost to the cathode end-plates so that the 'escape' of electrons is less



than with a ring anode; consequently, at any pressure, the ion current is larger. The narrow gap between the rims of the anode and the cathode plates leads to an increased electrostatic field and hence the primary current is larger. Consequently the critical or 'cut-off' pressure is lower than in the case of a similar gauge with a ring anode. Versions of this gauge with anodes as large as ten centimetres in diameter have been described by the Japanese¹¹ but the various

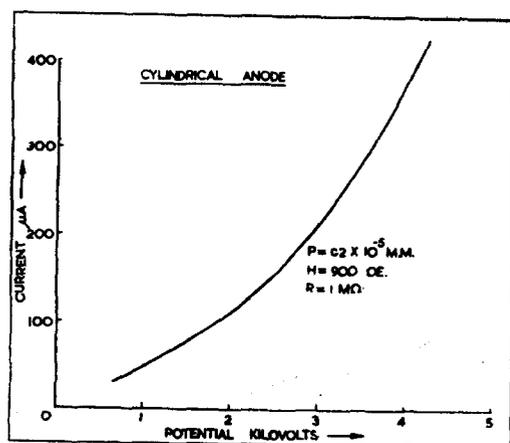


Fig. 2. Effect on the ion current of varying applied voltage (d.c.). Ring Anode.

possible modes of oscillation make gauges of this size somewhat unreliable. Leck at Liverpool University and Bloomer at the A.E.I. Laboratories, Aldermaston, have both concluded the model of Penning and Nienhuis was the best compromise between sensitivity and stability¹².

THE ELECTRICAL PARAMETERS

The Voltage

Each of the gauges illustrated in Fig. 1 shows a similar variation of current with applied voltage; Fig. 2 was obtained with a gauge of the earlier form of Fig. 1(a). The sensitivity of the gauge is increased by increasing the applied voltage, as one would expect, but the variation of ion current is not linear and above a certain voltage the discharge becomes unstable. For instance at a pressure of 5×10^{-6} mm. Hg the discharge and the current remain stable up to 4 kV. A similar curve, Fig. 3, shows the behaviour of gauges with the cylindrical anode illustrated in Fig. 1(b). In such gauges the voltage at which instability of the discharge becomes prohibitive is greater.

The stability of the discharge draws attention to a second merit of the cylindrical anode; it has already been noted that the sensitivity should be greater because the leakage of electrons is reduced. Changes in the modes of oscillation are responsible for instability of the discharge as may readily be verified by examining its changing appearance. Within a cylindrical anode the field is sensibly uniform while with a ring anode there will be small but appreciable gradients along the axis, even when the discharge operates. Increasing the voltage has a significant effect on the field gradient in the latter case but little in the former. Such distortion or change in the gradient excites higher modes of oscillation with consequent changes in the current. The primary

Fig. 3. Effect on the ion current of varying applied voltage (d.c.). Cylindrical Anode.

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Fig. 4. Effect on the ion current of varying applied voltage, showing the behaviour of the same gauge using alternating and direct voltages.

effect of increasing the voltage applied to gauges with a cylindrical anode is to increase the gradient in the immediate neighbourhood of the cathodes; the consequent increase in the cold emission has a stabilising influence on the discharge.

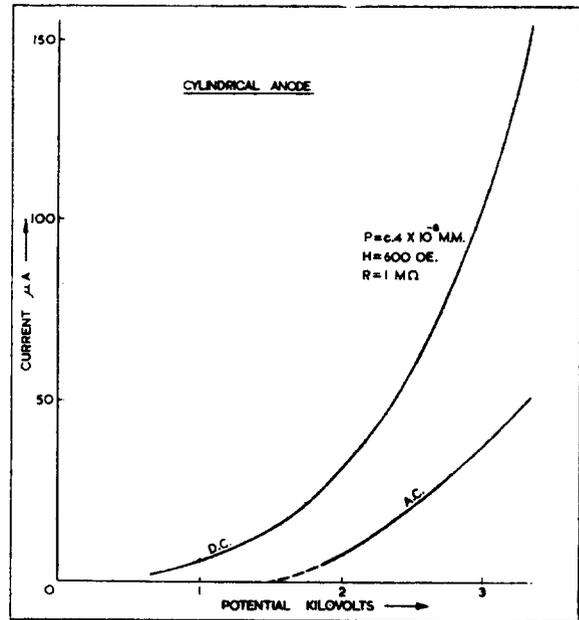
The measurements reported above were made using d.c. voltages. Since electron oscillations occur only if the end plates are at a negative potential, clearly the gauge will act as a rectifier if an alternating potential is applied to the electrodes. The gauge operates during that proportion of the correct half cycle in which the voltage exceeds the critical value for the pressure concerned. Moreover, during the other half cycle the polarity is such that ions are swept out of the field. At low pressures the phenomena associated with 'delayed ignition' referred to above, become more important and the discharge is extinguished at higher pressures than under d.c. operation. In our experience the sensitivity of a gauge operated on a.c. is much less than that of the same gauge operated on d.c. and the critical pressure is greater by a factor of about five. Fig. 4 shows the variation of current with voltage for the same gauge using d.c. and a.c. There are certain advantages associated with a.c. operation. The power unit is simpler and the precautions to limit leakage are less stringent so that the design and construction are a little simpler. Leakage leads to an a.c. current while the meter recording ion current responds only to d.c.¹³.

Save under exceptional circumstances it is preferable to use direct rather than alternating voltages. An exception must be made in the case of gauges designed for use at pressures of 10^{-3} mm. Hg or greater. These are considered later.

The Magnetic Field¹⁴

It appears from Fig. 5 that, under the conditions

Fig. 5. Effect on the ion current of varying the magnetic field. The Inset shows the shape near the maximum. The detail in this region is sensitive to changes of voltage and pressure. Cylindrical Anode.



specified, the discharge will not strike if the field is less than about 300 oersted. With low fields the performance is erratic; oscillation may occur in more than one mode and transition from one mode to the other is irregular. For reliable operation, fields of the order of 1,000 oersted should be used.

Changes in the mode of oscillation, irregularities of the field or small changes in the voltage rarely

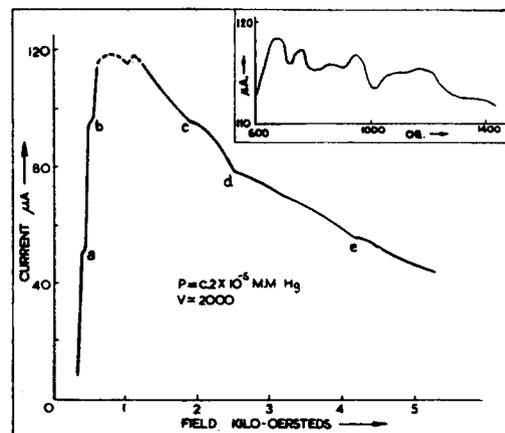
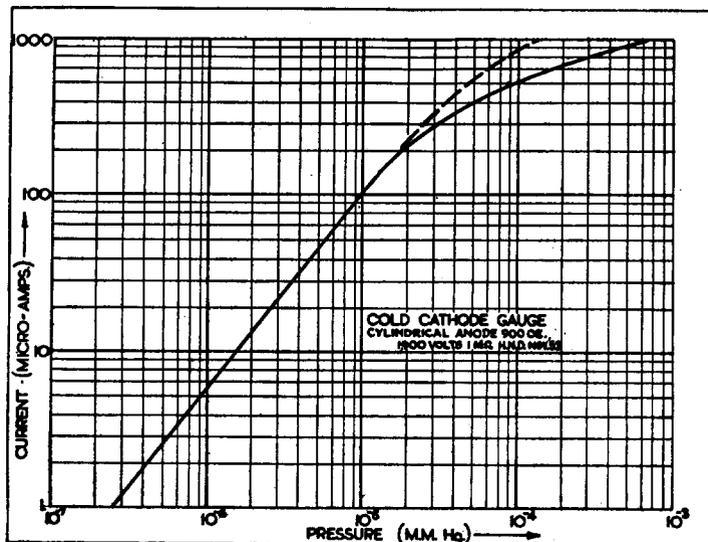


Fig. 6. A typical calibration curve for a Penning-type cold cathode gauge.



Voltage: 1,900; ballast resistor: 1 MΩ; magnetic field: 900 OE.

cause changes in current which exceed a factor of two. In most applications vacuum gauges are used to indicate the pressure range and for this purpose such variations are not important. For the same reason the magnetic field is not critical, though it should clearly exceed the value which corresponds to the maximum ion current. This depends on the geometry of the gauge and differs slightly for the three types shown in Fig. 1. Greater accuracy can be obtained, if necessary, by stabilising the electrical parameters.

The small irregularities revealed in Fig. 5 have no significant bearing on the performance but they are remarkable in that the changes in slope, a, b, c, d, e occur at values of the field strength which are independent of pressure and of voltage. These changes occur at the same values using different gauges of the same form. Pressure, voltage and uniformity of field influence the extent of these variations, not their position.

Over a wide range of pressure the relationship between current, i , and pressure, p , is of the form

$$p = C \cdot i^k$$

where C is independent of pressure and current. This relation is illustrated by the logarithmic graph

shown in Fig. 6. The departure from linearity at high pressures is determined by the magnitude of the ballast resistor. The variation given by the continuous line is obtained by reducing the pressure; when the pressure is raised this curve may not be retraced at pressures greater than 2×10^{-5} mm. Hg, as indicated by the dotted curve. In this region there may be a change in the mode of oscillation, accompanied by a change in the sensitivity from one curve to the other. According to Beck and Brisbane¹⁵, the index k depends on the magnetic field and approaches unity as this is increased. If the gauge is to have a scale which is linear with pressure, over a limited range, a magnetic field of the order of 2,500 oersted is desirable.

GENERAL COMMENTS ON GAUGES OF THE PENNING TYPE

Experimental evidence on the effect of changing the materials of the cathodes is less than decisive. Some authors have reported no change⁷; others state¹⁷ that gauges with nickel or constantan cathodes are not as sensitive as identical gauges with aluminium cathodes and that cathodes coated with magnesium oxide are more sensitive but less stable. The reported differences do not exceed 50% which is of

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little practical importance. In our experience there is no significant difference; we have not however carried out exhaustive tests since little significant change is to be expected. Sputtering is much reduced by using aluminium¹⁸. It may be noted that an aluminium cathode is invariably used in gas filled X-ray tubes.

As with all ionisation gauges, the nature of the gas affects the calibration. Fig. 7 shows ion currents plotted against pressure using different gases¹⁹. The curves are similar to those obtained with thermionic gauges. The differences among the various gases depend on the manner in which the probability of ionisation varies with voltage. If a gauge, calibrated with air, be used with a gas consisting mainly of organic vapours, the apparent pressure will be particularly high; such an instrument is not suitable for measuring low vapour pressures. Examination at various temperatures²⁰ emphasises that, although the ion currents are usually interpreted in terms of gas pressure, it is more accurate to consider the gas density. If the gauge is heated, the density of the gas is reduced, hence, since the number of molecules per c.c. is reduced, the ion current is reduced.

Reference has been made to oscillation of the electrons between the cathodes and as noted from time to time there are changes in the 'mode of oscillation'. There is frequent reference to such oscillations in the literature and, because of certain physical similarities, it is implied that these must be 'magnetron oscillations'. A gauge was constructed in which direct leads from each cathode were brought out separately through the envelope and extended to form a Lecher wire system. Changing the resonant frequency by moving the shorting strip between the two wires had no observable effect on the recorded current.

Electromagnetic radiation has been picked up by a loop placed near the gauge; there was no clear indication of polar distribution or of polarisation of this radiation. The 'noise' observed in this way occurs in a band, Δf , and such frequencies have been observed in the range 10 to 26 Mc/sec. In certain cases a much weaker signal is detected as a harmonic or a sub-harmonic of the main

signal. In a given gauge the frequency generated is a function of the magnetic field, voltage and pressure. At low voltages the discharge is weak and the resultant signal merges in the noise; with the intense discharge associated with high voltages the observed signals embrace a relatively large band Δf . For example using a field of 2,500 oersted no signal could be distinguished until the voltage exceeded 1,800; at 2,000 V, the frequency was 19.3 Mc/sec.; at 2,500 V, the signal extended over a range of about a megacycle at 22.1 Mc/sec. whereas at 3,000 V it extended continuously from 17 to 30 Mc/sec. Fig. 8 indicates the manner in which the frequency varies with changing magnetic field. These incomplete experiments confirm that the oscillations are plasma oscillations.

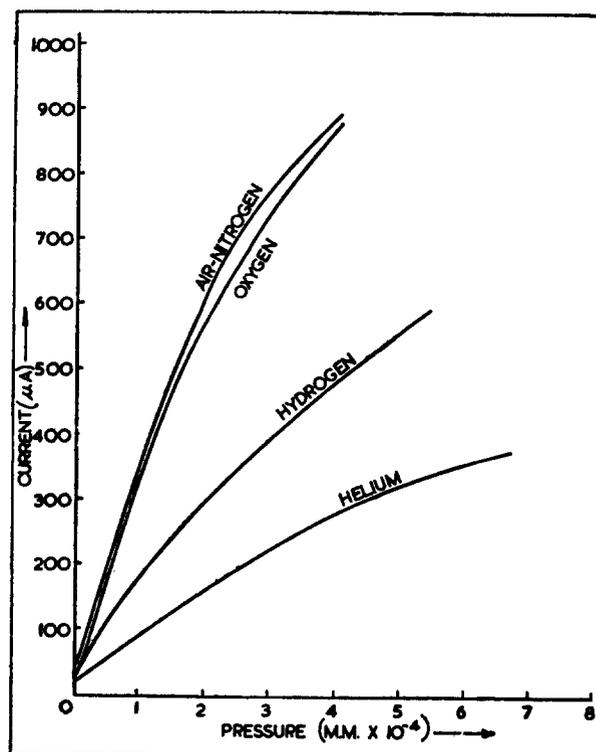


Fig. 7. Effect on the calibration of changing the gas in the gauge. L. R. Foote.¹⁹

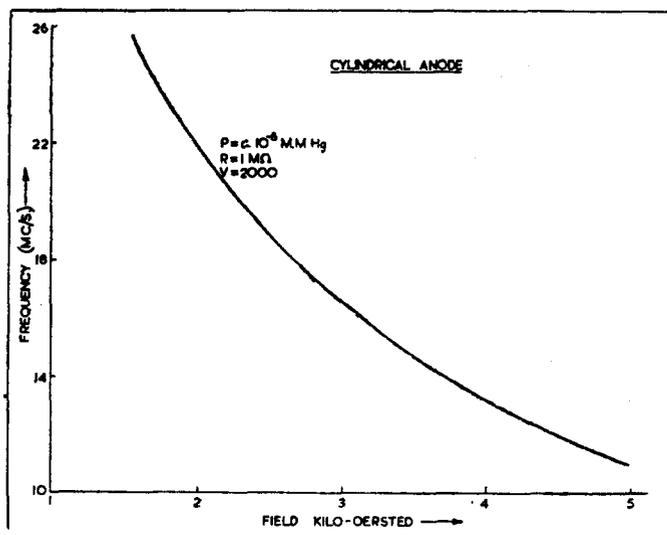


Fig. 8. Radiofrequency generated plotted against magnetic field.

primary current, about $0.06 \mu\text{A}$. The advantage is obtained at the expense of reducing significantly the exchange of gas molecules between the gauge and the vacuum system; effusion through the small holes in the cathodes is limited and the pressure recorded may well be too low. The later design of Broad²², overcomes this by using as anode a pointed rod which projects into the cylindrical cathode space the other end of which is open or alternatively closed with a wire mesh. Broad uses as his experimental parameter not the ion current but the voltage required to furnish a given ion current.

NEW MODELS OF COLD-CATHODE IONISATION GAUGES

In recent years a number of new gauges have been described which are, in essentials, variants of the Penning type of gauge. These new gauges have been described as 'magnetron' gauges since, like the magnetron, there is an axial magnetic field, and a central rod electrode with a second cylindrical electrode concentric with the first. The geometric similarity is misleading, however; in the magnetron the central electrode is the cathode, whereas in these gauges it is the anode.

Klemperer²¹ has described a gauge in which the cathode is a closed metal cylinder, the wire anode passing through a small hole in the centre of each circular end plate. The design of Beck and Brisbane¹⁵ resembles several such gauges mounted end to end with the addition of guard rings at the cathodes. The high electric field strength where the anode passes through the cathode ensures a high primary electron current. This, together with the fact that the probability of an electron escaping from the all-enclosing cathode is very small, ensures that the gauge has a low critical or 'cut-off' pressure. When operated at 6 kV, the current falls smoothly as the pressure is reduced until it reaches the value of the

From the published accounts it is not easy to compare these different gauges since the various authors quote calibrations obtained under different operating conditions. These conditions are not necessarily the best for the gauge concerned but may apparently be determined by the power supply and the magnetic field available. Thus the calibrations by Penning⁴ refer to a potential of 2 kV, those by Beck

Table I
(All figures refer to a pressure of 10^{-6} mm. Hg)

Gauge described by	Magnetic Field (Oersteds)	Potential (kV)	Ion Current (μA)
Penning and Nienhuis ¹⁰	370	2	6
	900	6	50*
Evans and Burmaster ²³	2,000	1.8	0.6
Klemperer ²¹	570	2	2
		3	4
		6	10
Beck and Brisbane ¹⁵	500	10	18
		2	< 1 §
		3	4.2
		6	21
Broad ²²	260	10	~46 §
		10	~70 §†

* Extrapolation based on a series of measurements, made in this laboratory with a gauge similar to that of Penning and Nienhuis.
 † Broad used a ballast resistance of $50\text{M}\Omega$.

and Brisbane¹⁵ of 3 or 6 kV and those by Broad²² of 10 kV. Table I is an attempt to compare the various arrangements; the values quoted are necessarily approximate and some are extrapolated from figures quoted in the published accounts.

GAUGES FOR USE AT HIGHER PRESSURES

An important feature of the gauges discussed in the previous sections is the lowest pressure at which they may be operated consistently. The same gauge is rarely required to measure pressures greater than, say, 10^{-3} mm. Hg. It is possible to design cold cathode gauges capable of operating up to and above 10^{-2} mm. Hg. In this case the leakage of electrons should clearly be increased. This is readily done by using a ring anode of small radius. Moreover the intensity of the discharge is high so that the sensitivity, (di/dp) , is not high unless the electrical parameters are altered appropriately. Most of the experimental information which is available on such gauges is given in a report by Dole²⁰ who suggests that a gauge of the original Penning design may be used at pressures up to 10^{-2} mm. Hg but that di/dp is small unless the ballast resistor is reduced to about 0.1 megohm, and the diameter of the anode ring is considerably smaller than the usual figure of one inch. The intensity of the discharge may be reduced by using lower voltages, of the order of one kilovolt. It cannot be emphasised too strongly that the behaviour at higher pressures is very sensitive to the magnitude of the ballast resistor.

Attention should also be given to a recent specification²⁴ in which a gauge to operate at higher pressures, up to 2×10^{-2} mm. Hg was constructed by designing the electrodes so that there is no straight path from one cathode to the other.

CONCLUSIONS

Cold cathode ionisation gauges provide a very convenient and simple means of measuring pressures between 10^{-2} and 10^{-7} mm. Hg, a given gauge with the appropriate power supplies and meters covering about four decades. The gauge itself is virtually indestructible if care is taken to prevent sputtered films from providing a conducting path between the two electrodes. Safety devices may be necessary to prevent damage to the current meter if a sudden influx of gas is likely to overload the meter.

Pressures as high as ten microns (10^{-2} mm. Hg) may be measured, using gauges with small anode rings, and relatively small ballast resistances. At the other end of the scale, the gauges are limited, apparently by the size of the primary electron current, to pressures greater than 10^{-8} mm. Hg. If electronic devices are used anywhere else inside the vacuum system, these must be shielded from the high voltages and from stray ions from the discharge.

The operating range of these gauges is similar to that of thermionic ionisation gauges. The ion currents are greater by two or three orders of magnitude, enabling more robust and cheaper meters to be used, and the gauges themselves are simpler, cheaper, and more difficult to damage than their thermionic counterparts.

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- ²⁴ ARNOLD, W. A., *U.S. Patent* 2,577,066 (1951).
'Pressure Measuring Device'.

ENGLISH



Arduino UNO & Genuino UNO

The UNO is the best board to get started with electronics and coding. If this is your first experience tinkering with the platform, the UNO is the most robust board you can start playing with. The UNO is the most used and documented board of the whole Arduino & Genuino family.

GETTING STARTED (</en/Guide/ArduinoUno>)

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Overview

5V 8-bit 16 MHz AVR

Arduino/Genuino Uno is a microcontroller board based on the ATmega328P (datasheet (<http://www.atmel.com/Images/doc8161.pdf>)). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.. You can tinker with your UNO without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again.

"Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the [Arduino index of boards](#).

You can find here (</en/Main/warranty>) your board warranty informations.

Getting Started

You can find in the Getting Started section (</en/Guide/HomePage>) all the information you need to configure your board, use the Arduino Software (IDE), and start tinker with coding and electronics.

Need Help?

- On the Software on the Arduino Forum (<https://forum.arduino.cc/index.php?board=63.0>)
- On Projects on the Arduino Forum (<https://forum.arduino.cc/index.php?board=3.0>)
- On the Product itself through our Customer Support (https://store.arduino.cc/index.php?main_page=contact_us&language=en)

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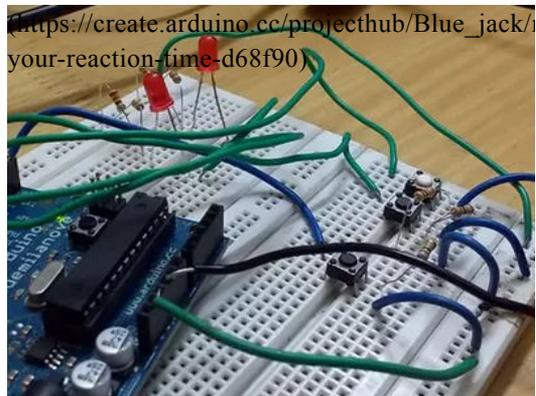
Security Access Using RFID Reader

by [Aritro Mukherjee \(/projecthub/Aritro\)](/projecthub/Aritro)
84,342 VIEWS 21 COMMENTS 94 RESPECTS



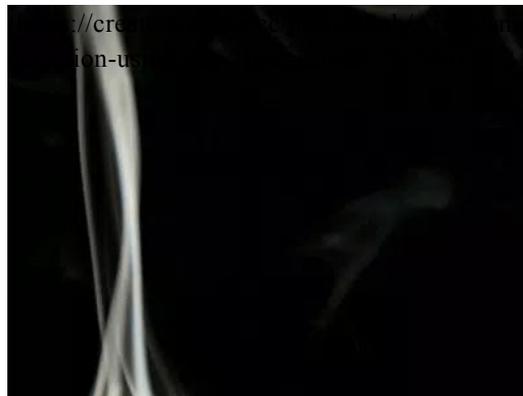
Arduino Kitchen Timer

(<https://create.arduino.cc/projecthub/I-and-myself>)
Project tutorial by [Team I and myself](#)
28,701 VIEWS 20 COMMENTS 39 RESPECTS



Measure your reaction time

(https://create.arduino.cc/projecthub/Blue_jack/my-reaction-time-d68f90)
Project tutorial by [Jayraj Desai \(/projecthub/Blue_jack\)](/projecthub/Blue_jack)
20,056 VIEWS 5 COMMENTS 17 RESPECTS



Smoke Detection using MQ-2 Gas Sensor

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60,119 VIEWS 17 COMMENTS 49 RESPECTS

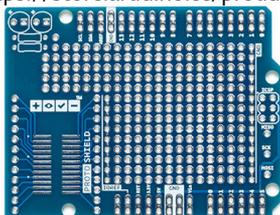
Related Items

The Arduino and Genuino family is so big! Check Arduino UNO related items and add them to your maker toolbox!
(<https://store.arduino.cc/product/C000089>)



ARDUINO/GENUINO UNO CASE

(<https://store.arduino.cc/product/TSX00083>)



PROTO SHIELD



USB CABLE

Technical specs

Microcontroller	ATmega328P (http://www.atmel.com/Images/Atmel-42735-8-bit-AVR-Microcontroller-ATmega328-328P_Datasheet.pdf)
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Documentation

OSH: Schematics, Reference Design, Board size

Arduino / Genuino Uno is open-source hardware! You can build your own board using the following files:

EAGLE FILES

IN .ZIP

(/en/uploads/Main/arduino_Uno_Rev3-02-TH.zip)

SCHEMATICS

IN .PDF

(/en/uploads/Main/Arduino_Uno_Rev3-schematic.pdf)

BOARD SIZE

IN .DXF

(<http://arduino.cc/documents/ArduinoUno.dxf>)

Programming

The Arduino/Genuino Uno can be programmed with the (Arduino Software (</en/Main/Software>) (IDE)). Select "Arduino/Genuino Uno from the Tools > Board menu (according to the microcontroller on your board). For details, see the reference (</en/Reference/HomePage>) and tutorials (</en/Tutorial/HomePage>).

The ATmega328 on the Arduino/Genuino Uno comes preprogrammed with a bootloader (</en/Hacking/Bootloader?from=Tutorial.Bootloader>) that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference (<http://www.atmel.com/Images/doc2525.pdf>), C header files (http://www.atmel.com/dyn/resources/prod_documents/avr061.zip)).

&SCOPE=PROFILE:CORE%20PROFILE:PUBLIC&RESPONSE_TYPE=TOKEN&REDIRECT_URI=HTTPS%3A%2F%2FWWW.ARDUINO.CC) You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header using Arduino ISP (</en/Main/ArduinoISP>) or similar; see these instructions (</en/Hacking/Programmer>) for details.

The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available in the Arduino repository. The ATmega16U2/8U2 is loaded with a DFU bootloader, which can be activated by:

- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then rese ing the 8U2.
- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode.

You can then use Atmel's FLIP software (<http://www.atmel.com/products/microcontrollers/default.aspx>) (Windows) or the DFU programmer (<http://dfu-programmer.github.io/>) (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial (<http://forum.arduino.cc/index.php/topic,111.0.html>) for more information.

Warnings

The Arduino/Genuino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Differences with other boards

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

Power

The Arduino/Genuino Uno board can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the GND and Vin pin headers of the POWER connector.

The board can operate on an external supply from 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may become unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- Vin. The input voltage to the Arduino/Genuino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- 5V. This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.
- 3V3. A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- GND. Ground pins.
- IOREF. This pin on the Arduino/Genuino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source or enable voltage translators on the outputs to work with the 5V or 3.3V.

Memory

The ATmega328 has 32 KB (with 0.5 KB occupied by the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library (</en/Reference/EEPROM>)).

Input and Output

See the mapping between Arduino pins and ATmega328P ports. The mapping for the Atmega8, 168, and 328 is identical.

(/en/Hacking/PinMapping168)

Each of the 14 digital pins on the Uno can be used as an input or output, using `pinMode()` (/en/Reference/PinMode), `digitalWrite()` (/en/Reference/DigitalWrite), and `digitalRead()` (/en/Reference/DigitalRead) functions. They operate at 5 volts. Each pin can provide or receive 20 mA as recommended operating condition and has an internal pull-up resistor (disconnected by default) of 20-50k ohm. A maximum of 40mA is the value that must not be exceeded on any I/O pin to avoid permanent damage to the microcontroller.

In addition, some pins have specialized functions:

- Serial: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the `attachInterrupt()` function for details.
- PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the `analogWrite()` function.
- SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication using the SPI library.
- LED: 13. There is a built-in LED driven by digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- TWI: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the `analogReference()` function.

There are a couple of other pins on the board:

- AREF. Reference voltage for the analog inputs. Used with `analogReference()`.
- Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

Communication

Arduino/Genuino Uno has a number of facilities for communicating with a computer, another Arduino/Genuino board, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The 16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required (/en/Guide/Windows#toc4). The Arduino Software (IDE) includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A `SoftwareSerial` library (/en/Reference/SoftwareSerial) allows serial communication on any of the Uno's digital pins.

The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino Software (IDE) includes a Wire library to simplify use of the I2C bus; see the documentation (/en/Reference/Wire) for details. For SPI communication, use the SPI library (/en/Reference/SPI).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino/Genuino Uno board is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino Software (IDE) uses this capability to allow you to upload code by simply pressing the upload button in the interface toolbar. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

The Uno board contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread (<http://forum.arduino.cc/index.php/topic,22974.0.html>) for details.

Revisions

Revision 3 of the board has the following new features:

- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible with both the board that uses the AVR, which operates with 5V and with the Arduino Due that operates with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

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What is Arduino?

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards ([//www.arduino.cc/en/Main/Products](http://www.arduino.cc/en/Main/Products)) are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language ([//www.arduino.cc/en/Reference/HomePage](http://www.arduino.cc/en/Reference/HomePage)) (based on Wiring (<http://wiring.org.co/>)), and the Arduino Software (IDE) ([//www.arduino.cc/en/Main/Software](http://www.arduino.cc/en/Main/Software)), based on Processing (<https://processing.org/>).

Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers - students, hobbyists, artists, programmers, and professionals - has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge (<http://forum.arduino.cc/>) that can be of great help to novices and experts alike.

Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments. All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software ([//www.arduino.cc/en/Main/Software](http://www.arduino.cc/en/Main/Software)), too, is open-source, and it is growing through the contributions of users worldwide.

Why Arduino?

Thanks to its simple and accessible user experience, Arduino has been used in thousands of different projects and applications. The Arduino software is easy-to-use for beginners, yet flexible enough for advanced users. It runs on Mac, Windows, and Linux. Teachers and students use it to build low cost scientific instruments, to prove chemistry and physics principles, or to get started with programming and robotics. Designers and architects build interactive prototypes, musicians and artists use it for installations and to experiment with new musical instruments. Makers, of course, use it to build many of the projects exhibited at the Maker Faire, for example. Arduino is a key tool to learn new things. Anyone - children, hobbyists, artists, programmers - can start tinkering just following the step by step instructions of a kit, or sharing ideas online with other members of the Arduino community.

There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and many others offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantage for teachers, students, and interested amateurs over other systems:

- **Inexpensive** - Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than \$50
- **Cross-platform** - The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.
- **Simple, clear programming environment** - The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with how the Arduino IDE works.
- **Open source and extensible software** - The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, you can add AVR-C code directly into your Arduino programs if you want to.
- **Open source and extensible hardware** - The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module ([//www.arduino.cc/en/Main/Standalone](http://www.arduino.cc/en/Main/Standalone)) in order to understand how it works and save money.

How do I use Arduino?

See the getting started guide ([//www.arduino.cc/en/Guide/HomePage](http://www.arduino.cc/en/Guide/HomePage)). If you are looking for inspiration you can find a great variety of Tutorials on Arduino Project Hub (<https://create.arduino.cc/projecthub>).

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Building an Arduino DC Voltmeter

MAY 12, 2014 BY JENNIFER MARSH

Multimeters and voltmeters are essential pieces of equipment when working on any kind of electronics circuit or Arduino project. A voltmeter measures the voltage between two points in a circuit and, with digital electronics, this is an analog range from zero to the level of the power supply (Vcc). Digital voltmeters work by converting the analog value to a digital value using an analog to digital converter (ADC). A typical Arduino has several of these converters on the board, and in this tutorial you will see how to read voltages from the Arduino's analog inputs and build a voltmeter that measures direct current (DC) voltages.



The circuit and information presented below assume a basic **knowledge of digital electronics and circuits**, and how to use an Arduino. **Learning the Arduino is a step-by-step** process, covering both programming in C and working with electronics circuits.

To complete the tutorial, you will need:

- An Arduino or Arduino-compatible board with analog inputs.
- The Arduino IDE (integrated development environment).
- One 100Ko resistor.
- One 10Ko resistor.
- Four wires, in at least two different colors (red and black are recommended).
- A breadboard (or suitable stripboard and soldering equipment).

In preparation, you should solder crocodile clips to two differently-colored wires, as this will make it easier to attach them to components when measuring voltages.

Working with electricity, even at low voltages, can be dangerous. There a risk of damage to equipment and yourself – follow the connection diagrams and instructions carefully, and always seek advice from a qualified and experienced adult if you are unsure.

The Arduino Sketch

To eliminate the possibility that the Arduino will run a previous sketch and operate in an unknown way, you can program the sketch first.

To create the voltmeter sketch:

1. Open the Arduino IDE.
2. Paste in the following code:

```

/*
 *
 * Udemy.com
 * Building an Arduino DC Voltmeter
 *
 */

float vPow = 4.7;
float r1 = 100000;
float r2 = 10000;

void setup() {
  Serial.begin(9600);

  // Send ANSI terminal codes
  Serial.print("\x1B");
  Serial.print("[2J");
  Serial.print("\x1B");
  Serial.println("[H");
  // End ANSI terminal codes

  Serial.println("-----");

```

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```

Serial.println("DC VOLTMETER");
Serial.print("Maximum Voltage: ");
Serial.print((int)(vPow / (r2 / (r1 + r2))));
Serial.println("V");
Serial.println("-----");
Serial.println("");

delay(2000);
}

void loop() {
  float v = (analogRead(0) * vPow) / 1024.0;
  float v2 = v / (r2 / (r1 + r2));

  // Send ANSI terminal codes
  Serial.print("\x1B");
  Serial.print("[1A");
  // End ANSI terminal codes

  Serial.println(v2);
}

```

And then save the sketch:

3. On the **File** menu, click **Save As...**

This sketch begins by initializing the serial port and declaring a few variables:

vPow – When powered over a USB cable, it is common for the Arduino's 5V power supply to be a little less than that ideal.

r1 – the value (in ohms) of the first resistor in the circuit.

r2 – the value (in ohms) of the second resistor in the circuit.

The sketch then sends some basic information to the terminal, and it displays the maximum voltage than can safely be measured by the current circuit.

The Serial Port Monitor in the IDE can be used to view the messages sent by this sketch. However, this is not a particularly advanced monitor, and cannot display the ANSI terminal sequences that are used to provide a friendlier display. Better results can be had by using a terminal package such as Hyperterminal, RealTerm or Putty.

The serial port you need to connect to can be found from the Arduino IDE:

- On the **Tools** menu, click **Serial Port** and look for the item that is ticked.

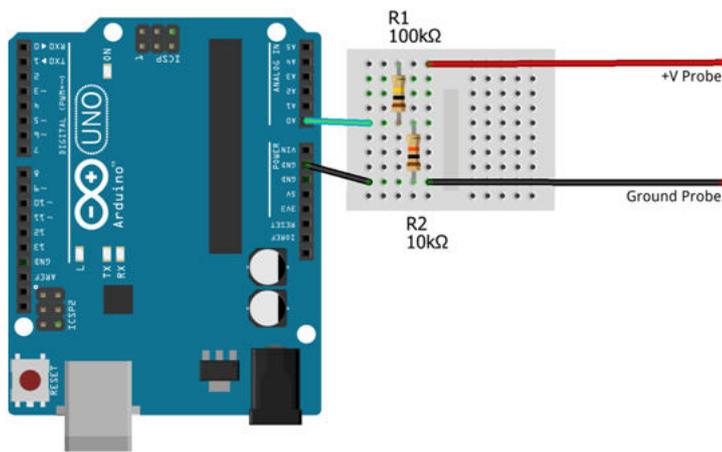
The other setting you should use are:

Display: ANSI
 Speed: 9600
 Parity: None
 Data Bits: 8
 Stop Bits: 1
 Hardware Flow Control: None
 Software Flow Control: None

Building the Circuit

Disconnect the Arduino from your computer before building this circuit!

The circuit can be constructed on a breadboard:



The analog inputs of an Arduino can measure up to 5V (when using the built-in analog reference voltage). Even when only connecting to a 5V circuit, you should use the resistors to help protect the Arduino from short-circuits or unexpected voltage surges.

Those two resistors form a potential divider that is used to lower the voltage being measured to a level that the Arduino can read. This actually extends the range that can be used. For example, if resistors are used to halve the input voltage then the Arduino can effectively read up to 10V (since 10V will be read as 5V, 5V will be read as 2.5V...). This comes at the expense of accuracy – the ADCs in the Arduino can read up to 1024 different levels between 0V and 5V. By expanding the range to 10V, those 1024 levels are spread across a wider range and are therefore less able to detect small changes.

You can increase the resistance value of R2, then the maximum voltage that can be read will be decreased; giving a slightly more accurate reading. With R1 at 100kΩ and R2 at 10kΩ, the input voltage is reduced by a factor of around 11 – allowing the voltmeter to read from 0V–55V.

The formula for calculating values in a potential divider is:

$$V_{out} = (R2 / (R1 + R2)) * V_{in}$$

If the divider for the Arduino voltmeter is functioning correctly then V_{out} will be a maximum of 5V, and so you can calculate the maximum input voltage to the circuit:

$$V_{max} = 5.0 / (R2 / (R1 + R2))$$

You can see a variation of this expression used in the `setup()` routine of the sketch.

Note: If you use different resistors from the ones suggested here, you must be remember to adjust the values of $r1$ and $r2$ in the sketch.

When measuring the voltage in the `loop()` routine, `analogRead(o)` is used to read the level from analog input 0. The returned value is an integer in the range 0 through 1023, so it must first be adjusted to a range 0 through 5. This is done by multiplying it by the power supply level, and then dividing by 1024.

To transform the 0V–5V value into a reading that reflects the range of values that can be measured by the circuit, the resistors must be taken into account in the same way as was done to calculate the maximum voltage the circuit could measure:

$$v2 = v / (r2 / (r1 + r2))$$

With all the calculations completed, the value now represents the actual voltage measured by the circuit, and is sent to the display.

Enhancing the Voltmeter

The voltmeter presented here is extremely basic and there is considerable room for enhancements, such as using switches to allow the user to choose from multiple potential dividers; adding an LCD display or a front-end in Processing; or building the meter using a minimal AVR circuit instead of a full Arduino board. **Arduino Step-by-Step** offers a more comprehensive look at the projects that can be created, and how to work with different types of components.

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