June 14, 2020

Dr. Craig Scratchley
School of Engineering Science
Simon Fraser University
British Columbia, V5A 1S6

photonicEyes

Subject: ENSC 405W Requirements Specification for SpecTro

Dear Dr. Scratchley,

The team at photonicEyes has prepared a requirement specification document for SpecTro for ENSC 405W. We aim to create an air particle detector that can analyze the shape, size and concentration of the particulates in the air. SpecTro is an industrial product that will aid industries such as the forestry, medical and construction industries in detecting damaging particulates in the air.

The basic idea is to use a light source and arrange several silicon photomultiplier (SiPM) detectors in an experimented geometry to measure the light that is reflected or diffracted through the particles in the air.

This software requirements specification will cover the requirements of the following stages:
(1) proof of concept (2) prototype, and (3) final product. It will present the requirements for our software and hardware, discuss safety and sustainability requirements and create an outline to allow for feasible completion for the deliverables for our project. We plan to establish feasibility by simulation to understand and visualize the systematic effects of the SiPM's in the measurement of light.

If any additional information or any questions of concern arises, please do not hesitate to inform us. We will be happy to be of assistance. Thank you in advance for your attention.

Regards,

On behalf of photonicEyes

Enclosure: Requirement Specification Report

SpecTro
Requirement Specification Document

Partners (PhotonicEyes):
Raheem Mian
Kurtis Raymond
Ahnaf Tahmid
Sazia Tasnim
Amirsaman Fazelipour

Sponsor:
Dr. Fabrice Retiere
TRIUMF

Submitted To:
Dr. Craig Scratchley
ENSC 405W
School of Engineering Science
Simon Fraser University

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Abstract

The goal of this document is to give the reader a detailed understanding of the requirements needed to realize the SpecTroproduct. The underlying principle as to the operation of SpecTroare explained, as well its intended purpose and its operation are shown, while also omitting details from the design specification. This document discusses the requirement specifications of which SpecTromust satisfy for successful operation. The relevant engineering standards, factors for sustainability, and safety factors that SpecTrowill need to satisfy are stated. Moreover, a detailed analysis of our acceptance plan to test these requirements are included.

Some of the key components for SpecTrowhich are discussed in this report include:

- General requirements
- Measurement requirements
- Control requirements
- Non-functional requirements
- Engineering standards requirements

Contents

List of Figures

Glossary

DAQ Data Acquisition System.

Impaction When small particles interfacing a bigger obstacle are not able to follow the curved streamlines of the flow due to their inertia, so they hit or impact the droplet.

OPC Optical Particle Counter.

PM Particulate Matter.

Quantum Efficiency The ratio of the number of carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell.

SiPM Silicon Photomultiplier, an array of SPADS.

Size Factor A parameter which compares the wavelength of light to the diameter of a particle.

$$\alpha = \frac{\pi D_p}{\lambda}$$

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SPAD Single Photon Avalanche Diodes. A high electric field region promotes a cascade of electrons per signal on the sensitive region. Provides 10^6 gain.

1 Introduction

Particles of many sizes exist in the air in various concentrations and can pose serious issues to health and safety, manufacturing reliability, and many other issues. The particular sizes of most interest are particulate matter at 2.5 μm ($PM_{2.5}$) and 10 μm (PM_{10}). These correspond to particulate matter which can enter the lungs, where they can remain for an almost permanent amount of time. Figure 1 shows the size chart for various types of particles:

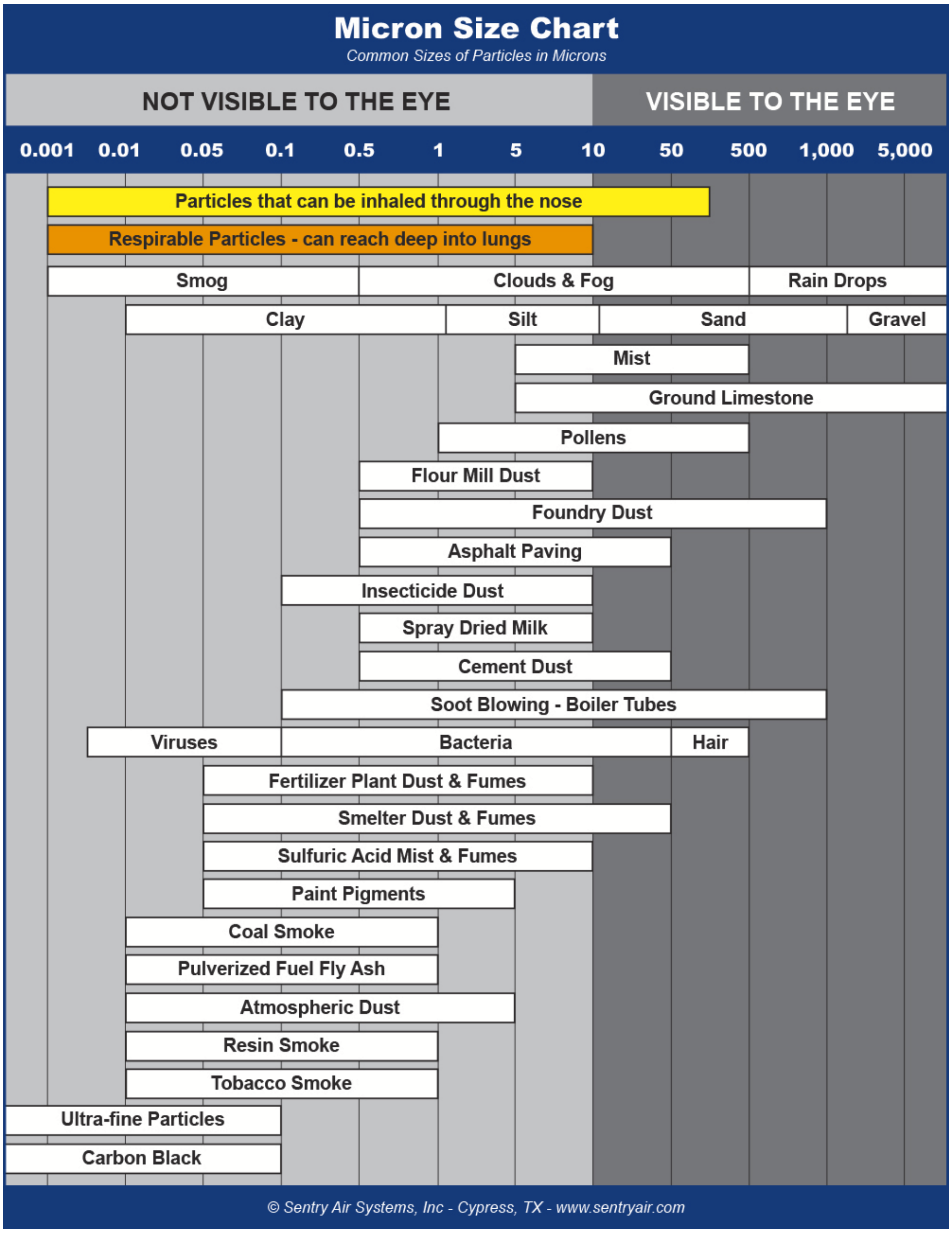

Figure 1: The size chart for various types of particles [1]

Most small particles, such as mould spores or suspended moisture drops, are nearly round objects. However, some conglomerate materials, such as those from smoke or ash, are smaller particles clumped together to form non-spherical shapes. We propose a particle detector that will be able to provide the concentration, size, and non-sphere shape of most particles in the 0.1um to 10um region.

1.1 Project Background

The foundations for this project are rooted in work done on a capstone [3] by three undergraduate students at UBC, where they established basic feasibility in the project. They constructed a basic proof of concept of a particle analyzer using a UV LED, and three UV sensitive SiPM's at unique angles. The LED was pulsed, and measurements of the scattered light were recorded. However, the proof of concept ultimately failed to replicate the theoretical scattering curve of their 1.03um and 0.49um particle test sources. A basic outline of the physics behind using light to measure the scattering is contained in the technical appendices.

The main issues the team at UBC found with the system were associated to light leakage, dark noise, dark current, and other sources. Our plan is to analyze these problems and find an appropriate solution through experimentation and simulation that can be feasible to the system. Investigation of potential solutions will include cost vs reward and reliability.

1.2 Intended Audience and Suggested Readings

This document serves the purpose of SpecTro's general functional and non-functional requirements for photonicEyes Inc. This report is featured to our esteemed potential clients, Dr. Craig Scratchley, Dr. Andrew Rawicz, and teaching assistants. Further research and data revisions will be provided from the specification layouts detailed in this document.

1.3 Document Conventions

Each main section organizes where the requirements should be located. Each subsection corresponds to an important subsystem of the product. Individual requirements have a label according to what point of the development they are required to achieve.

Label	Stage	Description
X.X.X P	Proof of Concept	Requirements to be met at the end of ENSC 405W
X.X.X E	Engineering Prototype	Requirements to be met at the end of ENSC 440
X.X.X F	Finish Product	Finished to market product

1.4 System Overview

Our requirements are organized in a cloud diagram in Figure 2. The specification requirements which follow are organized in terms of this diagram.

2 General Requirements

Requirements which underline the expectations of the entire system.

2.0.1 P	Be able to provide accurate measurements of $PM_{2.5}$ and PM_{10}
2.0.2 P	Must be able to provide measurements of transparent particles from 0.1um to 20um
2.0.3 P	Provide accurate concentration measurement binned by particle size
2.0.4 P	Provide a measurement of non-spherical shape binned by particle size

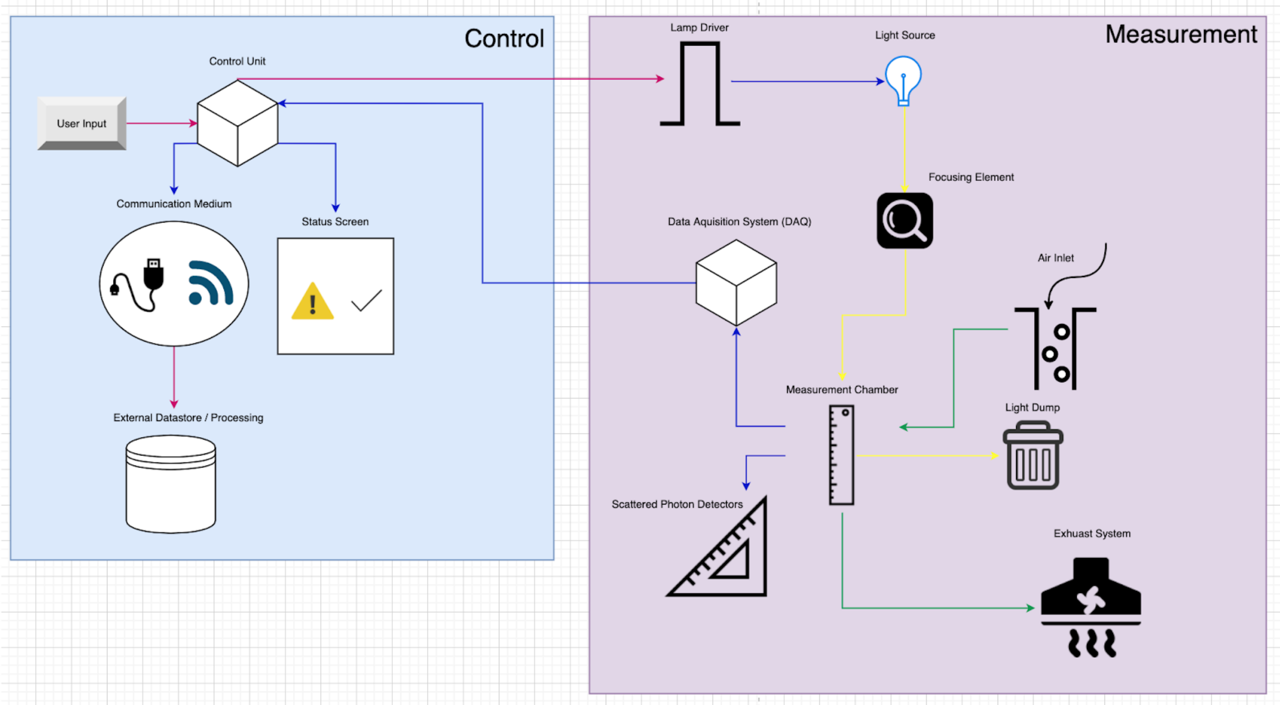

Figure 2: System Overview

3 Measurement

3.1 Air Inlet

Requirements related to the intake of air to be sampled are listed in this section.

3.1.1 P	The inlet is the only location in the enclosure which will allow air to flow in
3.1.2 P	Air should only flow into the inlet, and never out
3.1.3 P	The inlet must be light tight, ie allow no leakage of light
3.1.4 P	The inlet must prevent impaction of particles less than 100 um
3.1.5 E	Inlet should promote laminar flow as to avoid any statistical bunching of particles
3.1.6 F	Provide support for adding other particle analyzers in line, such as a Differential Mobility Analyzer, or other technologies which may aid in the classification of airborne particles.

3.2 Measurement Chamber

Requirements related to the airflow in measurement chamber to be sampled are listed in this section.

3.2.1 P	The sample air should not contaminate the measurement chamber
3.2.2 P	The sample chamber should take the laminar like air and transfer it to the exhaust.
3.2.3 P	The chamber should be light tight to prevent external light from being perceived as scattered light.
3.2.4 P	The measurement chamber must only contain connections to the air inlet, exhaust system, lamp, photon detectors, and beam dump to prevent contamination and potential light sources.

3.3 Exhaust System

Requirements related to the exhaust system are listed in this section.

3.3.1 P	The exhaust should put the measurement chamber at a negative pressure
3.3.2 P	The exhaust system should be light tight
3.3.3 P	The exhaust fan and motor should not contaminate the sample, or produce particles which could be potentially measured. Motor does not leak light.

3.4 Lamp Driver

Requirements related to Lamp Driver are listed in this section.

3.4.1 P	Provide a short pulse of electrical power to the lamp
3.4.2 P	Must not exceed the maximum electrical characteristics of the lamp
3.4.3 P	Produce an impulse like response into the lamp, thereby producing a fast strobe through the lamp.

3.5 Light Source

Requirements related to the properties of light source are listed in this section.

3.5.1 P	Produce a wavelength of light compatible with the photon detectors
3.5.2 P	Must use light from the UV band, and follow the safety concerns from ISO 15858:2016
3.5.3 P	Be stationary to avoid re-calibration of the focusing elements

3.6 Focusing Element

Requirements related to the focusing element are listed in this section.

3.6.1 P	Must have low absorption and high transmission in the UV band
3.6.2 P	Must provide low spherical aberration
3.6.3 P	Must focus UV light to a point at the center of the sampled air
3.6.4 P	Must diverge the light smaller than entry to the light dump

3.7 Light Dump

Requirements related to the properties of light dump are listed in this section.

3.7.1 P	Needs to prevent the reflection of more than 99% of the light impinged on it
3.7.2 P	The light dump must take in all non-scattered light which is not absorbed by particles
3.7.3 P	The light dump must provide some measure of extinction caused by absorbing particles.

3.8 Scattered Photon Detectors

Requirements related to the scattered photon detectors are listed in this section.

3.8.1 P	Must have a high Quantum Efficiency near the emitted wavelength of the lamp
3.8.2 P	The false trigger rate must be low enough as to not impact the scattering signal
3.8.3 P	Must measure multiple unique angles to construct the angular distribution of scattered light from particles.
3.8.4 P	Needs to have a high internal gain to simplify amplifier circuit and DAQcircuit.

3.9 Data Acquisition System DAQ

Requirements related to the DAQ are listed in this section.

3.9.1 E	The DAQ must have as many analog inputs as photon detectors
3.9.2 E	The DAQ must have all the digital outputs compatible with the control unit

4 Control Requirements

Requirements which underline the control system of the prototype.

4.1 Control Unit

Requirements related to the Control Unit are listed in this section.

4.1.1 E	Needs to be able to perform basic processing of data from the DAQ as required by the external devices, and status screen
4.1.2 E	The control unit must be able to export processed data to an external device
4.1.3 E	The control unit must be a low powered device, and must offload high workload tasks

4.2 User Input

Requirements related to the User Input are listed in this section.

4.2.1 P	The user input must be responsive at all times.
4.2.2 P	The system must respond to all forms of user input, even if the input would do nothing

4.3 Status Screen

Requirements related to the status screen are listed in this section.

4.3.1 P	The status screen should show basic diagnostic information such as $PM_{2.5}$ and PM_{10} concentrations, uptime, and other related information.
4.3.2 P	The status screen must visibly refresh at every user input, and at a specified time interval. This will give the impression of responsiveness.
4.3.3 P	The status screen should indicate sudden changes in concentration through some indicator

4.4 Communication Medium

Requirements related to the Communication are listed in this section.

4.4.1 P	The product must allow for the use of USB connectivity, and support emulated serial to allow for maximal compatibility between the product and external devices.
4.4.2 E	Allow for wireless communication to an app that allows external control of the product.

5 Non-Functional Requirements

Requirements related to the non-functional properties are listed in this section.

5.1 Normal Operating Conditions

Requirements related to the operating conditions are listed in this section.

5.1.1 P	The product should operate in an optimum room temperature
5.1.2 P	The product must not work in any medium other than air

5.2 Power

Requirements related to the power system are listed in this section.

5.2.1 P	The product should use no more power than is necessary for the sake of efficiency, as computations or processing can be exported to higher powered systems.

5.3 Size

The size of the product is yet to be determined. The proof of concept, and engineering prototype will likely be a desktop sized unit which can later be downsized.

5.4 Heat Dissipation

Requirements related to the thermal dissipation are listed in this section.

5.4.1 P	The product must not generate thermal currents which interfere with the sampling of the air.

5.5 Packaging

Requirements related to the packaging style are listed in this section.

5.5.1 F	The packaging must not have any sharp edges and loose components
5.5.2 F	The packaging must have inner cushion system to protect fragile item

5.6 Sustainability

Requirements related to the sustainability are listed in this section.

5.6.1 F	The product must use easy to recycle and re-purposed materials
5.6.2 F	The products deconstruction, maintenance, repairs, and servicing must be handled by SpecTro
5.6.3 F	The products size must be minimized to prevent overuse of raw materials
5.6.4 F	The product must be efficient and robust
5.6.5 F	Choice of constituent parts must include an assessment of the environmental impact
5.6.6 F	Follow the WEEE and RoHs directives.

5.6.1 Compatibility

Requirements related to the compatibility of the device are listed in this section.

5.6.1	The device should attempt to be as compatible as possible with other devices. This can be done through the use of using USB, and emulating a serial connection, for instance.

5.6.2 Limitations

Requirements related to the limitations of measurement are listed in this section.

5.6.1	The device will not be able to measure the size or shape of opaque particles from light scattering.

5.7 General Safety Considerations

In order to ensure the safety of our customers, and ensure legal sale of the device in Canada, united states, and the European union, several device standards must be met. The product must also supply a level of accuracy as stated in the specifications.

5.7.1 F	The product must reliably report the concentration of particles of specific sizes
5.7.2 F	The product must report non-sphericity of particles under-emphasis to reduce reliance. The shape of a particle should be used more as a diagnostic tool, not an objective measurement.
5.7.3 F	Must adhere to the safety guidelines set out in ISO 15858 (Exposure due to UV light)
5.7.3 F	Must be calibrated with a scheme compatible with ISO 21501-4 standard.

6 General Engineering Standards

The engineering standards necessary to satisfy regulator bodies, as well as maintain best practises are listed below.

ISO 14644-12:2018:	Clean rooms and associated controlled environments, Part 12: Specifications for monitoring air cleanliness by nano-scale particle concentration.
ISO 15858:2016:	Governs the amount of exposure of light from the UV band, and in particular the UVC band, which is shown to be absorbed in the first 2 μm of the stratum corneum. This needs to be followed for safety concerns.
ISO 21501-4:	"Determination of particle size distribution — Single particle light interaction methods, Part 4: Light scattering airborne particle counter for clean spaces". Used to set the standard for calibrating SpecTro.
ISO 14040 and **ISO 14044**:	These ISO standards are guide lines for the life cycle assessment, including a cradle to grave methodology
CAN/CSA-C22.2 No. 250.13-17:	Light emitting diode (LED) equipment for lighting applications
CAN/CSA-C22.2 No. 61508-1:17:	Functional safety of electrical/electronic/programmable electronic safety related systems, Part 1: General requirements
IEC TR 62471-2:2009:	Photobiological safety of lamps and lamp systems - Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety

7 Acceptance Plan

Acceptance test plans are attached at the end of the document.

8 Conclusion

In this document, the functional as well as non-functional requirements as well as the engineering standards, sustainability and safety components of the particle detector have been specified in detail. The requirements were broken down as follows. Measurement requirements such as air inlet, measurement chamber, exhaust system, lamp driver, light source, focusing element, light dump, scattered photon detectors, and data acquisition system DAQ. Control requirements such as control unit, user input, status screen, and communication medium. Non-functional requirements such as normal operating conditions, power, size, response time, heat dissipation, packaging, sustainability, compatibility, limitations, safety considerations. and user interface. Moreover, some of the technical issues were discussed, namely equations that model the behaviour of light scattering off of particles and Mie scattering. Some engineering details regarding the techniques which could be used to measure particulate size through measuring the angular variation in the intensity of the scattered light as it passes through samples have also been discussed in detail.

9 Technical Appendices

9.1 Light Scattering from Air Particles

The simplest case of inspecting scattering light off a transparent particle is to assume the particle is circular. A common figure of merit for the various regimes of scattering phenomena is the Size Factor which is given by:

$$\alpha = \frac{\pi D_p}{\lambda}$$

Where D_p is the diameter of the particle. When $\alpha << 1$, the wavelength is much greater than the diameter, and the system behaves geometrically. When $\alpha >> 1$, the wavelength is much larger than the spherical particle, and the light will scatter according to the intensity Rayleigh scattering law which is given by [4]:

$$I = I_0 \frac{1 + cos^2\theta}{2R^2} \left(\frac{2\pi}{\lambda}\right)^4 \left(\frac{n^2 - 1}{n^2 + 1}\right)^2 \left(\frac{D_p}{2}\right)^2$$

where I_0 is the initial intensity, and R is the distance from the particle to the observer. The region most important for optical particle counters is where $\alpha \sim 1$, which is known as Mie scattering. Conventional particles counters use this regime to provide particle sizing estimates. An example of the differing scattering patterns which may form are shown in Figure 3.

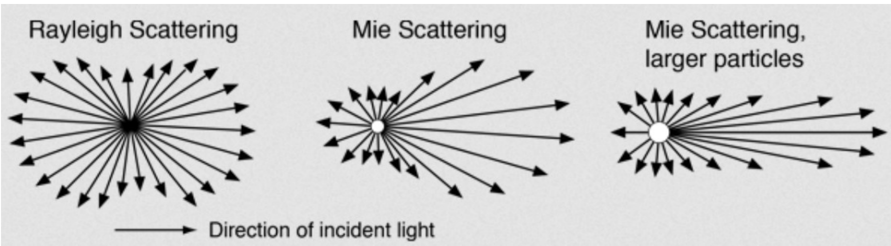

Figure 3: Rayleigh scattering and Mie scattering pattern [2]

These scattering intensities are assuming that the particles have some transparency, and do not absorb light. A case which violates this is carbon black, which will absorb the incoming light. In this case, another method will need to be used to identify the size of the particle, but a sensor directly across from the light source should be able to provide some notion of opaque particle concentration.

Since the formulation of Mie scattering is much more complex than Rayleigh scattering, and largely dependent on the size of the particle, several software packages exist which are able to provide angular scattering intensities. Some examples include MiePlot[5] or ADDA [6]. An Mie plot showing the radiative intensity of monochromatic light of wavelength 0.65 µm from spherical water drops of radius $r = 0.1\,\mu m - 1000\,\mu m$ is shown below in Figure 4 [5].

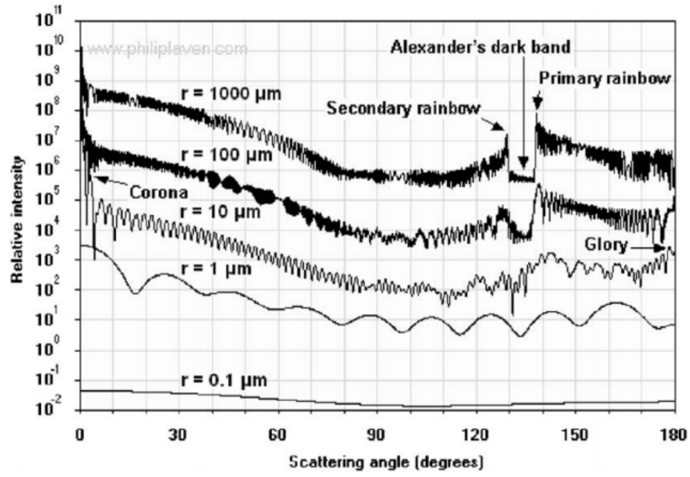

Figure 4: Mie plot of light scattering through spherical water drops

9.2 Scattering from non-spheroidal particles

Most air particles entering a particle counter will have some kind of surface tension which will cause the particle to assume a spheroidal shape. However, in some cases, transparent particles may assume a non-spherical shape. Examples of these could be small aspedose particles, or airborne bacteria. It is possible in principle that these types of particles will have a slightly perturbed scattering pattern from normal Mie scattering. A value of $\alpha = 3$ may provide enough of a perturbation enough to measure the shape of a particle [7].

References

[1] S. A. S. Inc., “Micron size chart,” Available at https://www.sentryair.com/micron-size-chart.htm (13 June 2020).

[2] “Hyperphysics: Mie scattering,” Available at http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html (14 June 2020).

[3] Q. W. Lin, I. Beckie, “Single photon air quality analyser,” January 6, 2020, engineering Physics Project Laboratory, UBC, Vancouver, British Columbia.

[4] P. n. Laven, “Rayleigh scattering,” Available at http://www.philiplaven.com/p8b.html (13 June 2020).

[5] P. Laven, “Simulation of rainbows, coronas and glories using mie theory and the debye series,” *J. Quant. Spectrosc. Radiat. Transfer*, pp. 257–269, 2004.

[6] Y. M.A. and H. A.G., “The discrete-dipole-approximation code adda: capabilities and known limitations,” *J. Quant. Spectrosc. Radiat. Transfer*, pp. 2234–2247, 2011.

[7] e. a. Schuerman, D. W., “Systematic studies of light scattering. 1: Particle shape.” *Applied Optics*, vol. 20, no. 23, pp. 4039–4050, 1981.

Test Sheet			
			Date:

General			
Accurate measurements of PM2.5 and PM10	☐ Yes	☐ No	Comments:
Accurate concentration of particle sizes (check size chart)	☐ Yes	☐ No	
Measured shape is correct (reference shape chart for particles)	☐ Yes	☐ No	
Air inlet			
Is air of a positive pressure	☐ Yes	☐ No	Comments:
Is air flow one way into the inlet	☐ Yes	☐ No	
Is light prevented from entering	☐ Yes	☐ No	
Particles less than 100 um prevented from impaction	☐ Yes	☐ No	
Laminar flow ?	☐ Yes	☐ No	
Measurement Chamber			
Does the sample air containinate the measurement chamber	☐ Yes	☐ No	Comments:
is streemlineness promoted ?	☐ Yes	☐ No	
is external light prevented ?	☐ Yes	☐ No	
Connections only to the air inlet, exhaust system, lamp, photon detector, and beam dump.	☐ Yes	☐ No	
Exchaust System			
Negative pressure applied to the assembly.	☐ Yes	☐ No	Comments:
Light tight	☐ Yes	☐ No	
Exhaust fan and motor do not contaminate the sample	☐ Yes	☐ No	
Lamp Driver			
Short pulse of electrical power to the lamp	☐ Yes	☐ No	Comments:
Below maximum electrical characteristics of the lamp	☐ Yes	☐ No	
Impulse like response into the lamp	☐ Yes	☐ No	

Light Source			
Produced wavelength of light compatible with the photon detector	☐ Yes	☐ No	Comments:
Light is used from UV band	☐ Yes	☐ No	
Light is stationary	☐ Yes	☐ No	
LED : 10 mA	☐ Yes	☐ No	
Focusing Element			
Low absorption in the UV band	☐ Yes	☐ No	Comments:
High transmission in the UV band	☐ Yes	☐ No	
Low spherical abberation	☐ Yes	☐ No	
UV light focused at the center of the sampled air	☐ Yes	☐ No	
Light diverged smaller than entry to the light dump	☐ Yes	☐ No	
Light Dump			
Prevents 99% of light reflected	☐ Yes	☐ No	Comments:
Placement is across the light source	☐ Yes	☐ No	
Scattered Photon Detectors			
High quantum efficiency near the emitted wavelength of the lamp.	☐ Yes	☐ No	Comments:
False trigger rate doesn't affect the scattering signal	☐ Yes	☐ No	
Angular distribution is constructed	☐ Yes	☐ No	
High internal gain	☐ Yes	☐ No	
Data Acquisition System (DAQ)			
Number of analog inputs = number of photon detectors	☐ Yes	☐ No	Comments:
Has all digital outputs compatible with control unit	☐ Yes	☐ No	
Has the tabulated and graphical representation of the I/O	☐ Yes	☐ No	
Control Unit			
Processing of data from DAQ, external devices, and status screen.	☐ Yes	☐ No	Comments:
Export processed data	☐ Yes	☐ No	
Low powered	☐ Yes	☐ No	
User Input			
Responsive at all times when powered	☐ Yes	☐ No	Comments:
Responds to user input	☐ Yes	☐ No	

Status Screen			
Displays diagnostics information (PM2.5,PM10,concentrations, etc.)	☐ Yes	☐ No	Comments:
Responsive to user input	☐ Yes	☐ No	
Sudden changes in concentration are indicated alarmly	☐ Yes	☐ No	
Communication Medium			
USB connection	☐ Yes	☐ No	Comments:
Emulated serial	☐ Yes	☐ No	
Wireless connection	☐ Yes	☐ No	
Normal Operating Conditions			
Operates at room temperature	☐ Yes	☐ No	Comments:
Not waterproof	☐ Yes	☐ No	
Heat dissipation			
Thermal currents are not generated	☐ Yes	☐ No	Comments:
Sustainability			
Follows the WEEE and RoHs directives	☐ Yes	☐ No	Comments:
Product is at a minimum size	☐ Yes	☐ No	
Products material is recyclable and can be repurposed	☐ Yes	☐ No	
Power			
Minimum power usage	☐ Yes	☐ No	Comments:
Safety			
Adheres to safety guidelines set out by ISO 15858	☐ Yes	☐ No	Comments:
Is calibrated corresponding to ISO 21501-4 standard	☐ Yes	☐ No	