CHAPTER 2

LITERATURE REVIEW AND RESEARCH BACKGROUND

This chapter presents an overview of previous scholarly literature related to the research. The review in this chapter covers light propagation in milk using various experimental and theoretical analyses.

2.1 Light Propagation

Light propagation is a phenomenon that occurs whenever the light transmits its energy from one point to another point (Meretska et al., 2017). This phenomenon leads to the occurrence of light absorption, transmission, and reflectance. The absorption of light is defined as the process of particles absorbing their light and converting it into energy, which is most likely turned into heat. On the contrary, the transmission of light is the ability of light to pass through any particles or object without being absorbed or scattered (Popoff et al., 2010). A perfect light transmission will cost the light not to lose any energy, which is considered 100% transmitted (Popoff et al., 2010). Figure 2.1 illustrates the phenomenon of light absorption.

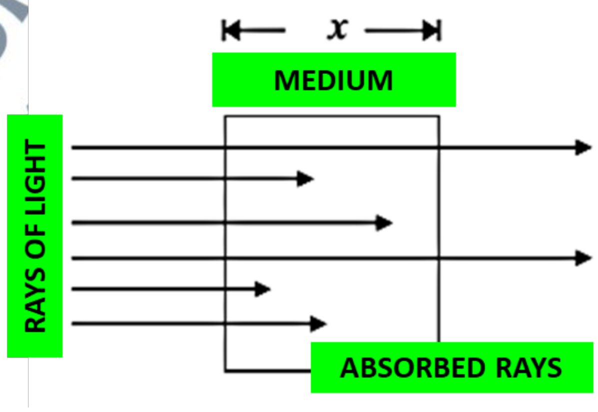
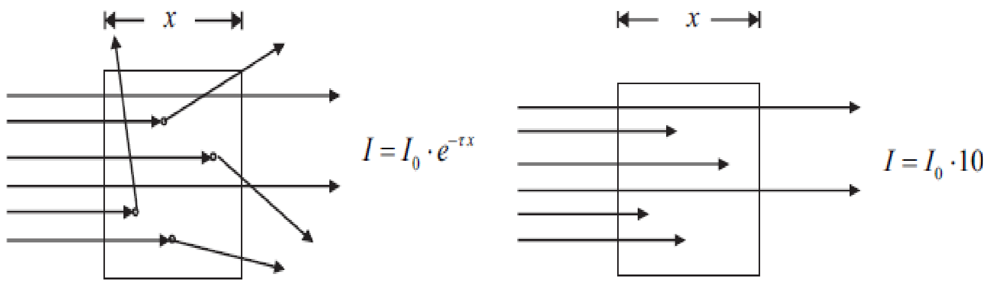


Figure 2.1: The Illustration of Light Absorption.

Based on (Øgendal, 2016), the light absorption refers to disappearance of photon after interacting with a particle, whereas light scattering is a change in the direction of a photon when light interacts with particle or molecule, as shown in figure 2.2. Transmission intensity, I decreases for both absorbed and scattered light. The attenuation due to absorption can be found using Equation (2.1) while the attenuation due to scattering can be measured using Equation (2.2) where I_0, α, and τ are the incident intensity before attenuation, absorption coefficient and turbidity respectively

$$I = I_0 \, . \, 10^{-\alpha x} \qquad (2.1)$$

$$I = I_0 . \, e^{-\tau x} \qquad (2.2)$$



(a) (b)

Source: (Øgendal, 2016)

Figure 2.2: Transmitted Light Is Disturbed by Either (a) Absorbance And (b) Scattering.

The exposure of a turbid medium to the light source causes the medium to change to hazy and cloudy states due to the presence of the insoluble and suspended medium. The high opaqueness of a medium causes the medium to become more turbid with high degradable of light intensity. Milk is an example of a turbid medium, one of the most consumed dairy products in the world. Fat, carbohydrates, proteins, and mineral contents in milk are important to develop a growth-mechanism effect and well-nourishes diet for mankind. Nevertheless, the role of milk as a nutritious food is questioned as the composition of milk that has been altered results in health problems. For example, full milk composition is being altered by adding water to increase milk volume, indirectly affecting the milk quality (Abegaõ et al., 2016). Meanwhile, a reflection of light occurs whenever light bounces back after hitting on an object (Yu et al., 2011). The reflected angle changes depending on the types of objects that had been hit. The smooth and shiny surface produce sharper reflection angle of the light, while the rougher and denser surface produces an uneven reflection angle, causing energy loss (Yu et al., 2011).

Research on light propagation increases from years to years. Recent studies on light propagation include research conducted by (Macêdo et al., 2020) on the unidirectional light propagation in natural crystals such as crystalline quartz. Besides that, (Hu et al., 2020) made an astounding finding by employing the 'twistronics' concepts to control the electrical properties by layering and twisting two-dimensional materials. The concepts are induced to manipulate the flow of light in powerful ways, generating more sophisticated light-driven technologies in the future. Furthermore, the stability of light propagation in optical fibres through the perspective of path memory and angular momentum was studied by (Ma & Ramachandran, 2021). Besides that, (Biton et al., 2021) did research on orbital angular momentum (OAM) through biological tissues.

On the other hand, this research focuses on investigating light propagation in milk samples to investigate milk quality based on the characteristics of light such as absorbance, transmission, and reflectance. All three light phenomena will be further investigated in this research to monitor milk quality through spectrometry experiments.

The absorption, transmission and reflectance of light can assist us to monitor the condition of milk. The changes in the absorption, transmission, and reflectance of light through the milk indicate the changing of milk condition. This matter provides a better and faster way of monitoring milk quality.

Thus, this research is continued from the previous work which aims to study the light propagation in various milk samples for different days of exposures in room temperature based on spectrometry techniques. The technique is simpler and cheaper than previous studies. Research methods which based on light propagation theory are convenient and non-intrusive as the methods do not affect or destroy the samples (Singh et al., 2013).

2.1.1 Fluorescence

Fluorescence is a form of photoluminescence, which is a phenomenon of light emission by a molecule that absorbed the energy of an incoming photon. There are two types of photoluminescence which are fluorescence and phosphorescence. Fluorescence occurs because of a molecule's radiative relaxation from an excited paired spin state to the ground state (Valeur, 2001), while phosphorescence stems from a radiative relaxation from a state of higher spin multiplicity. These two phenomena occur at different time scales. Fluorescence is a very fast process; it takes place on timescale around 10^{-9} s. It can be observed by eye only during excitation. Meanwhile, phosphorescence occupies a much broader time range. Therefore, it can be observed by eye for minutes or even hours after the excitation ended (Schulman et al., 2017).

Fluorescence spectroscopy deals with excitation and emission in molecules (Lakowicz, 2013). Any molecule can go into an electronically excited state when it is exposed to light of a wavelength (energy level) which is equal to the energy gap between the ground state and excited state. This is known as molecular absorbance of light (Lakowicz, 2013) (Schulman et al., 2017)The amount of light absorbed is proportional to the concentration of the absorbing molecule.

2.2 Light Scattering

Light scattering is a phenomenon that occurs whenever the light hits a small object (particle or molecule), resulting in a change of direction (Lenke & Maret, 2000). The scattering process is initiated as the photon is absorbed by the inhomogeneous medium, redirected away from the incident direction. The angular distribution of the scattered light is high due to the scattering regime and anisotropy factor (*g*) of the medium (Savo et al., 2018). The scattered energy might differ or be similar to its energy propagation, classified into elastic and inelastic scattering differentiated into two different regimes: the scatterers' size and light wavelength (Lenke & Maret, 2000). Figure 2.3 illustrates the changes in the direction of photons when light hits a particle or molecule.

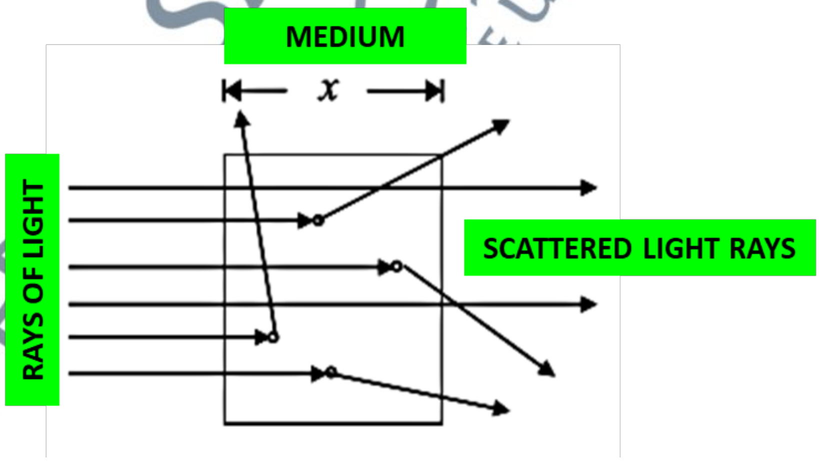


Figure 2.3: The Illustration of Light Scattering.

(Sardela, 2014) states that elastic scattering only changes direction without absorbing the energy. An example of elastic scattering is Rayleigh scattering, which happens when the particle size is smaller than the wavelength of light. The light is distributed consistently in all directions, and the two scattering types depend on the wavelength. Besides, its intensity is inversely proportional to the fourth power of wavelength, where its applications can be seen through the sky phenomenon and common dominants in a gaseous medium. Inelastic scattering involves Raman and Brillouin scattering, where the polarised molecule is due to vibration, and the electromagnetic radiation incident modifies rotating energy levels. The difference between these two scattering types is that optical photon is involved in Raman scattering, while the acoustic mode is responsible for Brillouin scattering (Sardela, 2014).

On the other hand, the characteristic of elastic scattering is vice versa of the inelastic scattering, where the particle size is larger than the wavelength of light, referring to the Mie scattering theory. It also suggests that a situation where the scattering particle size is comparable with light wavelength. Frequently, Mie scattering theory is used to compute the absorption coefficient μa, the scattering coefficient μs, and the phase function *p(θ)*, which is the direction of the photon being scattered, where θ is the scattering angle by anisotropy factor (Fukutomi et al., 2016). Mie scattering theory is highly non-uniform in angular distribution but is non-wavelength-dependent, where its scattering pattern focuses on the forward direction. Secondary peaks are observed based on the angular distribution due to the scattered waves interference (Lenke & Maret, 2000).

Light propagation theory is used in many research on milk quality involving spectrometry and optical fibers (Veenstra et al., 2020) had studied the scattering properties of human milk experimentally and numerically whereas (Kokotou et al., 2020) had developed a method through liquid chromatography–high resolution mass spectrometry to determine the free fatty acids in milk. Recent studies had conducted various spectrometry experiments to investigate the quality of milk. (Abohassan et al., 2021) designed a photonic crystal sensor to detect the fat volume in milk and (Frizzarin et al., 2021) used statistical machine learning methods to predict the cow's milk quality. However, the previous methods are not only complicated, but also focus on the cow's milk and certain wavelength of light spectrum.

Furthermore, many recent studies on light propagation in milk involve backscattering technique (Ansari & Mohajerani, 2011), external cavity-quantum cascade laser spectrometry (Montemurro et al., 2019) and laser diffraction and centrifugation (Ransmark et al., 2019). (Aljaafreh, 2015) introduced the simplified NIR spectrometry to measure the end of milk fermentation by transforming sugar to lactic acid. The key characteristics of the fermentation process consists of pH end point value, in the range of 4.4-4.5 (Aljaafreh, 2015). The techniques are quite complicated and costly. No comparison is done using milk after several days' exposure and water. The previous studies also do not provide theoretical approach on light scattering in milk. Our previous work (Muhamad Kamil et al., 2020) compared optical properties of full cream and skimmed milk using different types of spectrometers. We found that full cream milk has higher absorption due to higher fat content in it.

2.3 Milk Quality

Milk is one of the sources of a healthy diet because it contains lots of nutritional elements such as calcium, phosphorous, and vitamin D which are important for people from any age class (Bañuls et al., 2010). From infants to the elderly people consume milk as part of their daily diet as milk is the best source for calcium. Consuming milk is highly encouraged to build strong bones, teeth, muscles, and joints (St-Onge et al., 2009). The lack of calcium in our diet may lead to diseases such as osteoporosis, muscle cramps, and dental problems (St-Onge et al., 2009).

Besides that, the human body does not even produce calcium (Pravina et al., 2013). Therefore, a good calcium balance should be maintained based on the recommended daily intake to prevent fragility fractures (Byberg & Lemming, 2020). To maintain a healthy life, people need to gain calcium for their body. The best way is by consuming milk which leads to the rise of demand for the dairy industry. Table 2.1 depicts the recommended calcium intake required for bone health and maintains adequate calcium retention rates in healthy people per day.

Table 2.1: Recommended Daily Intake of Calcium.

Age	Male	Female	Pregnant	Lactating
0–6 months*	200 mg	200 mg		
7–12 months*	260 mg	260 mg		
1–3 years	700 mg	700 mg		
4–8 years	1,000 mg	1,000 mg		
9–13 years	1,300 mg	1,300 mg		
14–18 years	1,300 mg	1,300 mg	1,300 mg	1,300 mg
19–50 years	1,000 mg	1,000 mg	1,000 mg	1,000 mg
51–70 years	1,000 mg	1,200 mg		
71+ years	1,200 mg	1,200 mg		

* Adequate Intake (AI)

Source: (*Calcium Fact Sheet for Health Professionals*, 2021)

Milk can be processed and modified to produce more nutritious and scrumptious products to meet consumers, markets, and worldwide demand (Peterson et al., 2012). Some people cannot consume milk in its original form as they suffer from lactose intolerance (Scrimshaw & Murray, 1988). It happens when the body cannot digest the main carbohydrate in dairy products, which is lactose. It is suffered by 15-75% of human population due to the absence of lactase enzyme in their body needed to break down the lactose (Suarez et al., 1995). Therefore, milk is processed to meet every demand apart from extending its storage life, enhancing the taste and maximising the nutrition of the milk itself. The processed milk can be found in various form and taste such as cheese, yoghurt, flavoured milk, formula milk, and ice cream (Goff & Griffiths, 2006).

Hence, it clearly shows that monitoring milk quality is crucial and highly beneficial for maintaining the best healthy diet. Throughout the years, many scholars and researchers explored many methods to maintain and monitor milk quality. The tests and experiments such as Bulk Milk Bacterial Count, Bulk Tank Somatic Cell Count, California Mastitis Test, and Milk Conductivity Test had been performed for the sole purpose of maintaining the quality of milk (Kaşikçi et al., 2012). As the dairy industries have chains of workers for the whole production process of dairy products, from the farm to the shelf of consumers, it is the source of nutritious food (Lore et al., 2006).

Therefore, it is proven that milk quality is a vital element to be monitored and maintained so that humans worldwide could benefit nutritiously and financially. Table 2.2 shows the summary of previous research on milk. Most of the research focus on cow's milk and use one spectrometry technique only, thus, the study on milk in plant-based milk other than cow's milk is important. Comparison of optical properties of milk based on various types of spectrometry techniques is also needed to have a comprehensive study on characteristics of milk.

Table 2.2: The Summary of Previous Research on Milk.

Researcher	Study	Research Gap /Limitation
(Gowri et al., 2019)	(Fiber optic milk fat sensor) Developed a hand-held, susceptible fibre optic milk fat sensor using U-bent plastic optical fibre (POF) probes based on the refractive index (RI) of milk.	The research was conducted only on one type of milk and more complicated. The study was conducted using optical fibre only based on the RI of milk.
(Choudhary et al., 2019)	(Spectrometry technique) Developed a fluorescence-based technique that is fast, sensitive, and effortless, in order to study the time-based milk degradation at room temperature.	The research only covers the fluorescence-based spectrum. The research was conducted on one type of milk and more complicated.
(Shuso Kawamura et al., 2013)	(Spectrometry technique) Developed an alignment model for anticipating three significant milk constituents (fat, protein, and lactose), somatic cell check (SCC), and milk urea nitrogen (MUN) of unhomogenised milk.	The research is costly, performed with only one type of spectrometer and also conducted only for cow's milk.
(Mohammadi et al., 2014)	(Ultrasound technique) Analytical ultrasound included the checking and quality control of dairy items dependent on the physicochemical varieties during storage or preparation. High-intensity ultrasound had been utilised for handling applications like sanitisation, homogenisation, fermentation, and extraction.	The research conducted was more complicated, high cost and focused on the frequency-based only. The experiments were also conducted only for one type of milk.
(Vimalajeewa et al., 2018)	(Spectrometry technique) Used Fog figuring to deal with information near the farm and infer ranch experiences by trading information between on-ranch applications and moving some information to the cloud.	The study focusses on milk fat, lactose, protein, and urea which is more complicated and high cost. Using only one spectrometer type for the

	Mid-infrared spectroscopy (MIRS) is utilised internationally to foresee a few milk quality boundaries just as determining numerous creature level aggregates.	experiments and conducting the research only on the cow's milk.
(Gunasekera et al., 2003)	(Spectrometry techniques) Distinguished cell types using the principle of flow cytometry (FCM) coupled with fluorescence techniques. Immunised the well-known contributor of numerous microscopic organisms or mouse cells. For bacterial investigations, protein and lipids were taken out, while diffusive lipid clearing was required for physical cell examinations.	Focusing only on the frequency-based study and Principal Flow Cytometry (FCM). The research was expensive, complicated, and only conducted for one type of milk.
(Toffanin et al., 2015)	(Spectrometry techniques) Milk samples were collected individually and examined by inductively coupled plasma optical emanation spectrometry (ICP-OES) and titration for the assurance of calcium (Ca), phosphorus (P), and titratable corrosiveness (TA) substances, separately.	The forecast models only based on Mid-infrared spectroscopy (MIRS) and the research was more expensive, complicated, and only conducted for one type of milk.

2.3.1 Types of Milk

Various types of milk are consumed globally. Milk can be classified into animal-based and plant-based milk (YİĞİT, 2019). Animal-based milk is derived from mammals' consumable milk glands, while plant-based milk is pasteurised from plant sources. Table 2.3 below shows the example of animal-based and plant-based milk.

Table 2.3: Examples of Animal-Based and Plant-Based Milk.

Animal Based	Plant-Based
Cow Milk	Almond Milk
Goat Milk	Oat Milk
Sheep Milk	Soy Milk
Goats Milk	Hemp Milk
Buffalos Milk	Rice Milk
Donkey Milk	Coconut Milk

Milk has initially been secreted from mammals such as cows, sheep, and goats to be consumed for the past 10000 years (Silanikove et al., 2015). The luxurious taste and nutritional elements in milk had made it favored and cherished by millions of consumers worldwide. This situation led to the inspiration of producing the alternative milk that suits vegan consumers and the people who suffer from allergy from mammals' milk, such as lactose intolerance (Silanikove et al., 2015). Plant-based milk is vegan-friendly as it does not contain the carbohydrates and cholesterol in the mammal's milk (Mäkinen et al., 2016). Plant-based milk gains popularity among consumers as it has a creamy texture and luxurious taste, more environmentally friendly and less prone to having allergies (Sethi et al., 2016).

Besides that, plant-based milk can be altered to match the taste, texture, and the same nutrients as animal-based milk (Sethi et al., 2016). Despite being the alternative to healthier and eco-friendly milk choice, plant-based milk is still human-made. Plant-based milk such as almond milk, oat milk, and soy milk are just almond, oat, and soy processed with water, minerals, and vitamins (McCarthy et al., 2017)(Vanga & Raghavan, 2018). The biggest downside of plant-based milk is to catch up with cow's milk flavour, texture, and taste. Thus, lots of sugar and additives are added throughout the process (Verduci et al., 2019).

On the other hand, plant-based milk is much more expensive compared to animal-based milk as producing plant-based milk is made from scratch and requires much cost (Roberto et al., 2006). The gap in oat milk price in the market is around twice to thrice times the cow's milk, causing people to find it hard to keep consuming plant-based milk as part of their daily diet.

2.3.2 Milk Ingredients / Contents

As animal-based milk and plant-based milk may vary significantly in terms of their nutrients and contents after being processed, it is advisable to find the best milk based on your own needs and preferences in maintaining a healthy diet. The composition of raw mammal's milk is tabulated in Table 2.4.

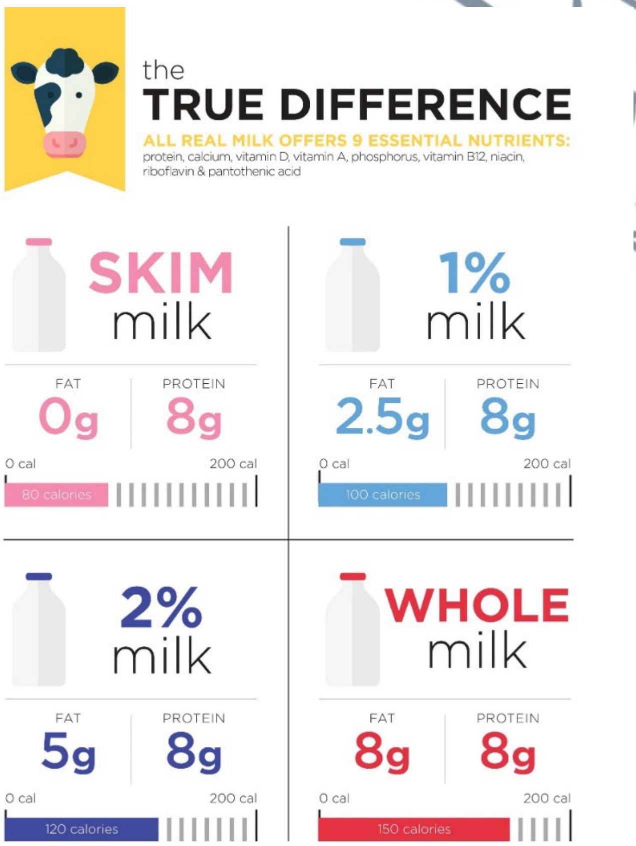
Table 2.4: The Composition of Raw Milk from Different Species of Mammals In g/100g Of Milk.

Species	Water	Proteins	Fat	Lactose
Cow	87.2	3.5	3.7	4.9
Sheep	82.7	5.5	6.4	4.7
Goat	86.5	3.6	4.0	5.1
Camel	87.7	3.5	3.4	4.7

Source: (YİĞİT, 2019)

Raw mammal milk cannot be easily imitated regardless of the texture, taste, and nutrients (YİĞİT, 2019). Therefore, to achieve the desired standard of animal-based milk, plant-based milk had been processed and altered thoroughly (Haas et al., 2019). Nevertheless, animal-based milk also goes through many alterations and modifications to enhance the flavors and the taste to be easier to consume while improving storage life (Harding, 1995).

Whole milk (3.25%), reduced-fat milk (2%), low-fat milk (1%), and skimmed milk (0%) are examples of milk altered with different values of fat content but having the exact value of protein (8g), respectively. Figure 2.4 shows the visual differences between altered cow's milk fat content, while Table 2.5 shows the nutrition fact chart for 240 ml of cow's milk, almond milk, oat milk, and soy milk.



Source: https://milklife.com/articles/nutrition/types-of-dairy-milk

Figure 2.4: The Differences Between Altered Cow's Milk Fat Content.

Table 2.5: Nutritional Composition of Cow's Milk, Almond Milk, Oat Milk and Soy Milk as Per 240ml.

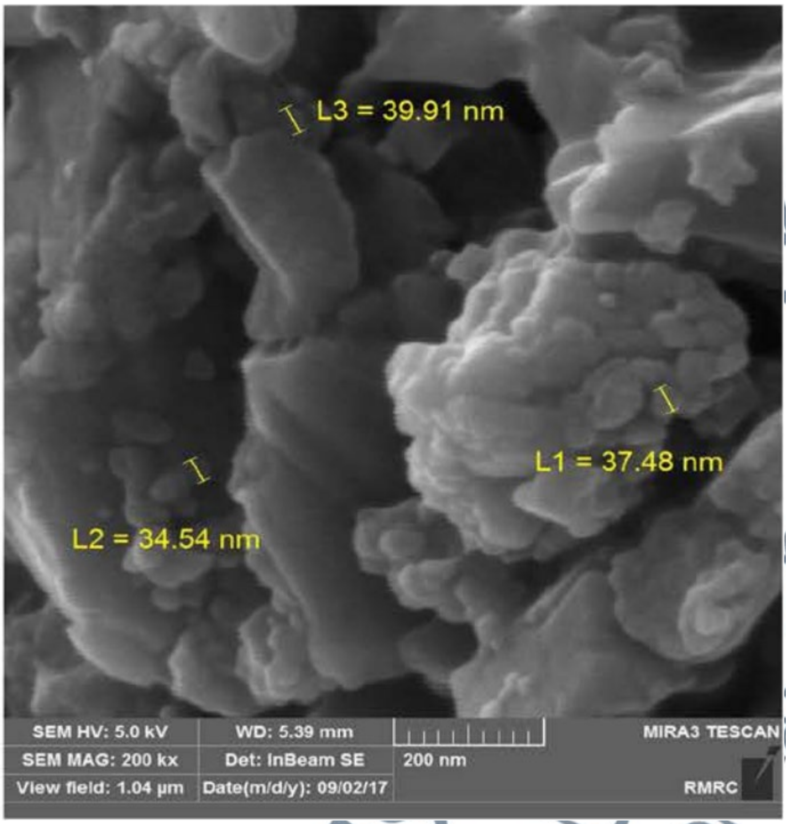
Nutrition Content	Cow's Milk	Almond Milk	Oat Milk	Soy Milk
Product	2% with Vitamin A & D	Califia Farms Original	Pacific Original	Silk Original
Energy (Kcal)	122	59	130	100
Protein (g)	8.05	1.00	4.01	8.0
Fat (total g)	4.83	4.01	2.50	4.01
Saturated (g)	3.067	0	0	0.501
Carbohydrate (g)	11.71	6.00	24.00	7.99
Fiber (g)	0	0.9	1.9	1.0
Sugars (g)	12.35	5.00	19.01	6.00
Calcium (mg)	293	450	350	299
Iron (mg)	0.05	0.71	1.80	1.07
Magnesium (mg)	27	N/A	N/A	39
Potassium (mg)	342	N/A	120	299
Sodium (mg)	115	161	115	119
Riboflavin (mg)	0.451	0.434	0.509	0.510
Vitamin B12 (mg)	1.29	3.01	N/A	2.99
Vitamin A (IU)	464	500	499	501
Vitamin D (IU)	120	100	101	119

Source: (Bridges, 2018)

2.3.3 Milk Fermentation

Milk fermentation occurs when milk undergoes the conversion of carbohydrates to alcohols (lactose to lactic acid), carbon dioxide or organic acids using yeasts, bacteria, or all of these combinations, which is under anaerobic conditions (Svendsen et al., 2015). The bacteria in milk gains energy from lactose, producing more bacteria, turning lactose into lactic acid (Weston, Kuchel, et al., 2020). This makes milk become curdle and tastes sour to indicate that the milk may no longer be consumed (Weston, Phan, et al., 2020). The fermentation of milk to yoghurt can generate productivity control and high product quality insurance, which can only be achieved by in-line monitoring in the fermentation process (Svendsen et al., 2015).

During the fermentation process, the milk turns into a semi-solid medium like yoghurt texture. Whenever the milk state turned into such a yoghurt texture, the milk particles will be aggregated during the coagulation (Thomsen et al., 1990) (Hahn, Krzeminski, et al., 2012). Lactic acid will be produced when the milk protein thickens, and the bacteria causes the milk to decay, experiencing a decrease in pH level (Liu & Smallwood, 2011). Salmonella, E. coli, and Listeria are examples of diseases caused by consuming spoiled milk (Pakdaman et al., 2020). Figure 2.5 shows the electron microscopy image of the curdled milk after the fermentation process occurs.



Source: (Shirani et al., 2020)

Figure 2.5: The Electron Microscopy Image for Curdled Milk.

Therefore, it is crucial to distinguish between spoiled milk and fresh milk to prevent stomachache, diarrhea, and vomiting disease (Pakdaman et al., 2020). In this research, the quality of milk before and after fermentation is compared where changes in the particles size and the milk condition are main factors of the milk quality. The milk quality can be measured through light absorbance, reflectance and transmission using spectrometry experimental method.

2.4 Spectrometry

Spectrometry is a method used to measure the spectral power distribution of electromagnetic radiation and the interaction between light and matter (Malara et al., 2020). Many types of spectrometers vary in terms of their specialisation and physical characteristics. Mass spectrometers, optical spectrometers, electron spectrometers, and magnetic spectrometers are examples of various types of spectrometers invented to measure the wavelength and frequency of light (McIntosh, 2017). There are many types of spectrometers, with many possible variations and modifications which are specialized in different applications. The region of the electromagnetic wave spectrum that had been usually used are X-ray, UV-VIS (Ultraviolet–Visible), IR (Infra-Red), and microwave.

The spectrometry method was first discovered by Newton when he studied the radiation of white light that split up into various shadings while going through a crystal (Bakar et al., 2016). From that point forward, a few analysts applied the spectrometry rule to portray various natural marvel, including the spectra of sun, stars, flares, and sparks. Spectrometry method was widely used after 1852, when a Baugouer-Bee-Lambert law was developed. The numerical estimation of spectral absorption measurement leads to colorimetry, photometry, and spectrophotometry methods (Perkampus, 1992).

Spectrometry techniques are used in many experiments to detect light properties such as absorption, transmission, reflectance, and fluorescence at any desired wavelength, frequency, and energy (Osborne, 2006). During the interaction between the light and the samples, the incident light can be absorbed by, reflected off, or transmitted through a sample (Yaqoob et al., 2008). Thus, characteristics/optical properties of the sample can be investigated through light intensity from the spectrometry experiments.

Besides, a spectrometer can be used to measure particle composition and distribution size for a sample (Zou et al., 2021).

Therefore, spectrometry is widely used to measure the optical properties of samples based on light propagation, fluorescence, or colour spectrometry. It is used to obtain the information about the atoms and molecules (Aljaafreh, 2015) (Alshammari et al., 2020). The absorbance spectrometry (Alshammari et al., 2020) is a technique used to measure amount of absorbed light (Nadareishvili et al., 2020) with the determination of solution concentration based on Beer's Law (Bakar et al., 2016). NIR spectrometer and VIS-NIR spectrometer with different ranges of wavelength are used to determine the accuracy of the intensity spectrum in the spectrometry analysis (Viscarra Rossel et al., 2006).

2.4.1 UV VIS and FTIR Spectrometer

UV-VIS and FTIR studies the absorption of light of the sample. UV (Ultra-violet) spectrophotometers use visible light to determine the concentration of chemicals in a mixture while FTIR (Fourier-Transform Infrared Spectroscopy) uses infrared light for the same purpose (Valentino & Sobrado, 2019). An UV-VIS spectrometer is very similar with the IR spectrometer in many ways as both spectrometers study the absorbance of the matter and having the similar instrumentation. Fourier-transform infrared spectroscopy (FTIR) analysis is done to study the chemical compounds such as C=C and O-H in milk samples. Through FTIR, the unsaturated fatty acid and water element in the samples were analyzed. In most cases, a sample used in spectrometric analysis must be pure to avoid confounding results.

2.4.2 Spectrometry Experiments in Milk

The spectrometry technique also had been applied to monitor food quality. The authentication of raw milk from reconstituted milk has been done using FTIR spectrometry (Du et al., 2019). The effectiveness of mid-infrared spectrometer is analysed and results show mineral compositions of bulk milk (Malacarne et al., 2018). Many spectrometry analyses are done on milk samples including Laser spectrometry (Montemurro et al., 2019), Fiber-optic spectrometry (Katsumata et al., 2020), Micro-electromechanical systems (MEMS)-based Fourier Transform Infra-Red (FTIR) spectrometers sensing (Amr et al., 2018) and Raman spectrometry (Vaskova et al., 2016) in order to characterize milk fat. There are many applications based on spectrometry analysis such as the use of Fourier Transform Infra-Red (FTIR) to identify the mineral drug substance (purified bentonite) in a drug product (Ouhaddouch et al., 2019) and to analyse the chemical properties of *"Nicotiana plumbginifolia"* as an important element in ethnomedicine (Sayani Chandra, 2019). Table 2.6 summarises the previous research on various spectrometry experiments to investigate the properties of milk and other materials.

Table 2.6: Summary of Previous Research Using Various Types of Spectrometry Experiments.

Researchers	Spectrometry Technique & Study	Research Gap /Limitation
(Ohtani et al., 2005)	(Fibre-optic spectrometry) Used fiber-optic probe and sensor to measure the milk fat content by analysing 183 types of milk samples with a specified temperature at the wavelength range of 400nm-1100nm. The results showed that the internal reflectance ratio obtained with visible light is suitable for measuring milk fat content.	The experiments are more expensive, complicated, using only one type of spectrometers and focusing only on cow's milk.

(Russell, 2013)	(MicroNIR1700 and MicroNIR2200 spectrometer (870 – 1660 nm and 1130 – 2150 nm)) Measured the composition of raw milk using online milk sensor. The original MicroNIR spectrometers could not predict fat and protein to International Committee for Animal Recording (ICAR) precision limits for an online sensor. Thus, the light output should be increased, and cooling was required to reduce the operating temperature.	The research uses only one type of spectrometers and focuses only on cow's milk.
(Brandão et al., 2010)	(FTIR and NIR Spectrometry) Observed the optical characterization of milk in order to evaluate its composition and it was proven that that the wavelength 2308 nm could be used to determine the fat concentration of milk without other components influence.	The research is complex. It focuses only on cow's milk.
(Aljaafreh, 2015)	(Near-Infrared spectrometry) Measured the end of the milk fermentation via the transformation of sugar to lactic acid.	The research onlystudies the optical properties of milk based on NIR spectrometry and focusing only on cow's milk.
(Malacarne et al., 2018)	(Mid-infrared spectrometer) Mid-infrared spectroscopy (MIRS) was used to predict detailed mineral composition of bovine milk. However, the MIRS proved to not able to predict the detailed mineral composition of bulk milk with sufficient accuracy, especially for those minerals that are present at low concentrations.	This research uses only mid-infrared spectrometer and focuses only on cow's milk.
(Zughaibi & Steiner, 2020)	(Orthogonal-acceleration time-of-flight (oaTOF) mass spectrometer) Differentiated multiple (7) types of nylon using direct analysis in real-time (DART) with the Orthogonal-acceleration time-of-flight (oaTOF) mass spectrometer analysis.	The research is complicated and using only one type of spectrometers. The research is conducted to investigate nylon composition instead of milk.

(W. Zhu et al., 2020)	(Raman spectrometer). Developed a susceptible surface-enhanced Raman spectroscopic SERS technique for the rapid quantification of creatinine levels in human urine.	The research uses one type of spectrometers, and the research is conducted to investigate human urine composition instead of milk.
(Y. Wang et al., 2021)	(Micro near-infrared (NIR) spectrometer). Evaluated the quality of tea qualitatively and quantitatively.	The research uses only one type of spectrometers, and the research is conducted to investigate tea composition instead of milk.

2.5 Theoretical Analysis

In the theoretical analysis, the modeling techniques are used to analyse the light propagation in milk. Many modeling techniques can be used to investigate the light propagation, such as Monte Carlo Simulation (Ramachandran et al., 2004) (Kuz'min et al., 2019), Whittle–Matérn (WM) Correlation Function (Floden, A, Combs, 2012), Finite Element Modeling (FEM) (Floden, A, Combs, 2012) and Finite Difference Transport (FDT) (Ramachandran et al., 2004). (Xu et al., 2006) investigated light propagation models to determine the optical properties of tissue. The authors selected the Monte Carlo simulation as the best models among four of the tested models. Therefore, Monte Carlo simulation was applied in this research.

Theoretical analysis on milk is widely used to investigate the milk quality for monitoring and predicting purposes. The model of milk coagulation process had been demonstrated by (Lyndgaard et al., 2012) to demonstrate the real-time coagulation process and simulating the production situation. Besides that, the theoretical modeling for locating the binding sites of citric acid and gallic acid on milk was done by (Chanphai & Tajmir-Riahi, 2020). Results showed that acid binds protein via ionic contacts with gallic acid forming stronger protein conjugates. On the other hand, (Gorbunova et al., 2020) proposed a model that was able to calculate the concentration of enzymes of milk reductase sample with resazurin while (Mekmene et al., 2010) made a simulation model of ionic equilibra. The partition of salts between the aqueous and micellar phases of milk from the estimated root-mean-square error (RMSE) and a slope closed to a unit that were obtained.

2.5.1 Monte Carlo Algorithm

According to Merriam Webster (*Monte Carlo*, n.d.), Monte Carlo is initially retrieved from the name of a city in Monaco famously known for casinos and gambling. For the simulation context, the Monte Carlo is the synonym of randomness, like gambling randomness. Thus, Monte Carlo Simulations are defined as the simulations evolving randomly (Kenton, 2020) and used to estimate a random or uncertain possible outcomes for an event. (Rorger Eckhardt, 1987). The Monte Carlo method was first invented during World War II (in 1946) by John von Neumann and Stan Ulam to improve decision-making under uncertain conditions. Stan Ulam was recovering from an illness and playing solitaires when he got the first inspiration to calculate the probability of withdrawing a Canfield solitaire with 52 cards in the deck (Rorger Eckhardt, 1987).

Monte Carlo Simulation can be used in many different situations to estimate the outcome with a high uncertainty level in the results. The examples of application of the Monte Carlo method are electron transport (Kawrakow, 2000), risk and uncertainties when managing projects (Kwak & Ingall, 2007) (Arnold & Yildiz, 2015), and sensitivity analysis (Pham et al., 2019). However, a few rules should be followed to ensure the effectiveness of the method (Vatsal, 2021), which are:

I. The dependent and independent variables will be identified and defined as per their domain of possible inputs.

II. The probability distribution is determined before generating inputs over the domain randomly.

III. The output for the problem will be calculated based on the randomly generated inputs.

IV. Repeat the experiment for *N* number of times and aggregate the results.

Thus, Monte Carlo simulation was chosen for this research because it can estimate the outcome for the random media.

Light propagation in milk samples can be modeled based on Monte Carlo technique. Monte Carlo method applies the stochastic model that analyses the random probability distribution or pattern which is not precisely predicted (S. Prahl & Keijzer, 1989). Monte Carlo algorithm offers a randomized statistical sampling to solve the complex structure in milk composition besides being widely used to study biological materials such as human tissues (Meretska et al., 2017).

2.5.2 Mie Scattering

Scattering can be divided into elastic and inelastic scattering (Bednyakov & Naumov, 2018). Elastic scattering occurs when the direction of light propagation is modified, and the photon energy is conserved. In contrast, inelastic scattering changes the direction of light and the photon energy (Kozák, 2018). Elastic scattering can be described using Rayleigh, Mie, and Geometrics optics modeling. These three types of modeling depend on the size of nanoparticles. Rayleigh scattering model is used for elastic light scattering when the particle diameter is much smaller than the wavelength of the scattered light (Cox et al., 2002). Meanwhile, the Mie scattering model is used to analyse the particles for spherical nanoparticles with the size being almost the same as the light wavelength. Moreover, Geometrics optics studied the particles with a much larger radius than the light wavelength (Cox et al., 2002).

In this research, the Mie Scattering theory is used to investigate the absorption coefficient, scattering coefficient, and scattering angle of the milk samples (J. Wang et al., 2020). As Mie scattering is solely dependent upon the particle size (Moosmüller & Sorensen, 2018) and the wavelength of light, this research applies Mie theory to suit the conditions needed to investigate and monitor the milk samples. Equation (2.1) shows the equation for scattering cross-section based on Mie theory (Cox et al., 2002).

$$\sigma_{sM} = \left(\frac{2\pi}{k^2 m}\right)\sum_{n=1}^{\infty}(2n+1)(|\alpha_n|^2 + |b_n|^2) \tag{2.1}$$

The a_n and b_n are the scattering coefficients found in (Cox et al., 2002) while $k_m = 2\pi n_m/\lambda$.

Mie scattering theory is used to compute the absorption coefficient (μa), the scattering coefficient (μs), and the phase function *p(θ)*, where θ is the scattering angle (Kienle et al., 1996). Mie theory is used to calculate the spectral dependence for the extinction cross section of the nanoparticle suspensions (Ramanenka et al., 2020). The pump source energy can pass through the turbid media depending on the optical properties of the media such as the refractive index, scattering, anisotropic factor, and the absorption of the laser light (Ansari & Mohajerani, 2011). The optical properties of milk based on backscattering intensity can be used to study fat and protein concentrations (Ansari & Mohajerani, 2011). The complex fluid of milk is made up of many components such as water, lipids, lactose, and protein (Montemurro et al., 2019) (Jensen et al., 1991)(Ransmark et al., 2019).

2.5.3 Random Lasers

Laser is an optical device used in our daily lives, such as laser surgery, bar code scanners, laser range finding and laser material processing. A regular laser requires a cavity for the feedback mechanism (Meystre & Sargent, 1990). Q-switched mode-locking laser based on absorber mirror and double Q-switched laser using mixed crystals are the examples of various types of lasers. Those lasers are developed and improvised to improve the laser properties (Ismail et al., 2019). The random laser depends on multiple light scattering and optical gain to provide the feedback mechanism and light amplification respectively (Burin et al., 2001). With the fantastic properties of emission possessed by the random laser that is more powerful than a regular laser and almost the same as a lightbulb, its demand has risen these days (Wiersma & Cavalieri, 2001).

Random lasers consist of two types: incoherent and coherent feedback (Ismail et al., 2014). Incoherent random lasers work when the light returns to the gain medium by multiple light scattering (Wan Ismail, 2020). The photon density rapidly grows with the pumping rate increment, where a narrowed emission peak is formed on the broad fluorescence background at the centre of the gain spectrum during threshold (Ismail et al., 2014). Meanwhile, the coherent feedback in random laser occurs when the scattered emission light produces the closed-loop paths (Kedia & Sinha, 2017) due to repetitive light scattering, resulting in the emergence of narrow spectral peaks above the emission background when the lasing threshold occurs (Wiersma, 2008) (Consoli & López, 2015).

Random lasers have unique characteristics such as low fabrication costs, a specific wavelength of operation, flexible shape, and substrate compatibility made them easily adapted to many fields (Van Hoang et al., 2010). This laser is the future of laser technology as the development creates more advanced applications and provide more job opportunities worldwide (Y. Zhu et al., 2020). Bioimaging, tumour detection, image quality test, and contrast-to-noise ratio (CNR) tests are examples of applications where random lasers appear to be in high demand due to their promising features which enhance the technology (Van Hoang et al., 2010). Random lasers are crucially useful in biosensing and medical applications since the lasers can be mass-produced and convenient to set up and handle at a low cost (Wan Ismail et al., 2020). Thus, random lasers can develop many new and sophisticated applications to befit niche marketing needs due to their unique characteristics.

A random laser is one of the alternatives developed to improve the performance of a regular laser by operating on multiple light scattering and optical gain instead of a cavity (Lee et al., 2019). The multiple light scattering and optical gain provide feedback and the light amplification respectively where particles scatter the light and the light is confined and amplified by stimulated emission (Ismail et al., 2019). The characteristics of random lasers can be observed through lasing threshold, emission linewidth and emission spectra. The lasing threshold is reached when the energy transition is saturated where the emission linewidth reduces nonlinearly with the increase of pump energy. When the system reaches lasing threshold, the multiple emission peaks appear on top of the fluorescence background (Tian et al., 2019)(Wan Ismail et al., 2020) (Choubey et al., 2020).

The random laser has many benefits such as simple set up and low cost leading to its suitability to be used in biosensing and imaging applications (Wan Ismail et al., 2015)(Chen et al., 2021) . Research on random lasers include the usage of biological membranes (Chen et al., 2021), fibers (Popov et al., 2020) (Wan Ismail et al., 2020), polymers (Gummaluri et al., 2020) and dyes (Kedia & Sinha, 2017b) (Ismail et al., 2019). Random lasing in er-doped rayleigh fiber was recently achieved by using a weak fiber Bragg grating (FBGs) that uniformly distributed over the fiber length. Meanwhile, (Chen et al., 2021) had developed a facile method to improve the performance of a biological photonic crystal random lasers for speckle-free imaging. Besides that, random laser modeling based on light scattering in milk is also done using light propagation theory.

2.6 Conclusion

In conclusion, the brief reviews on light propagation, milk quality, milk contents, Mie theory, Monte Carlo algorithm and random lasers are given in this chapter. Various methods to study on milk either using spectrometry or others are reviewed. Further reviews and theoretical studies are also provided in Chapter 3 until Chapter 5 to have better understanding on each part so that the objectives can be achieved. Basically, the milk quality and milk contents can be investigated through light propagation theory using experimental and theoretical approach. The difference amount of contents in milk samples contribute to the difference in absorbance, transmission and reflectance spectra. Besides that, the characteristics of fresh milk and fermented milk can easily be distinguished through this study which indirectly help on studying and monitoring the quality of milk. Therefore, study on milk quality and its content is important not only for consumers but also for dairy industries.