Wiarygodność naukowa

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Plan wypowiedzi:

- Etyka w nauce
- Poprawność języka naukowego
- Polemika naukowa
- Relacja z promotorem
- Własność intelektualna

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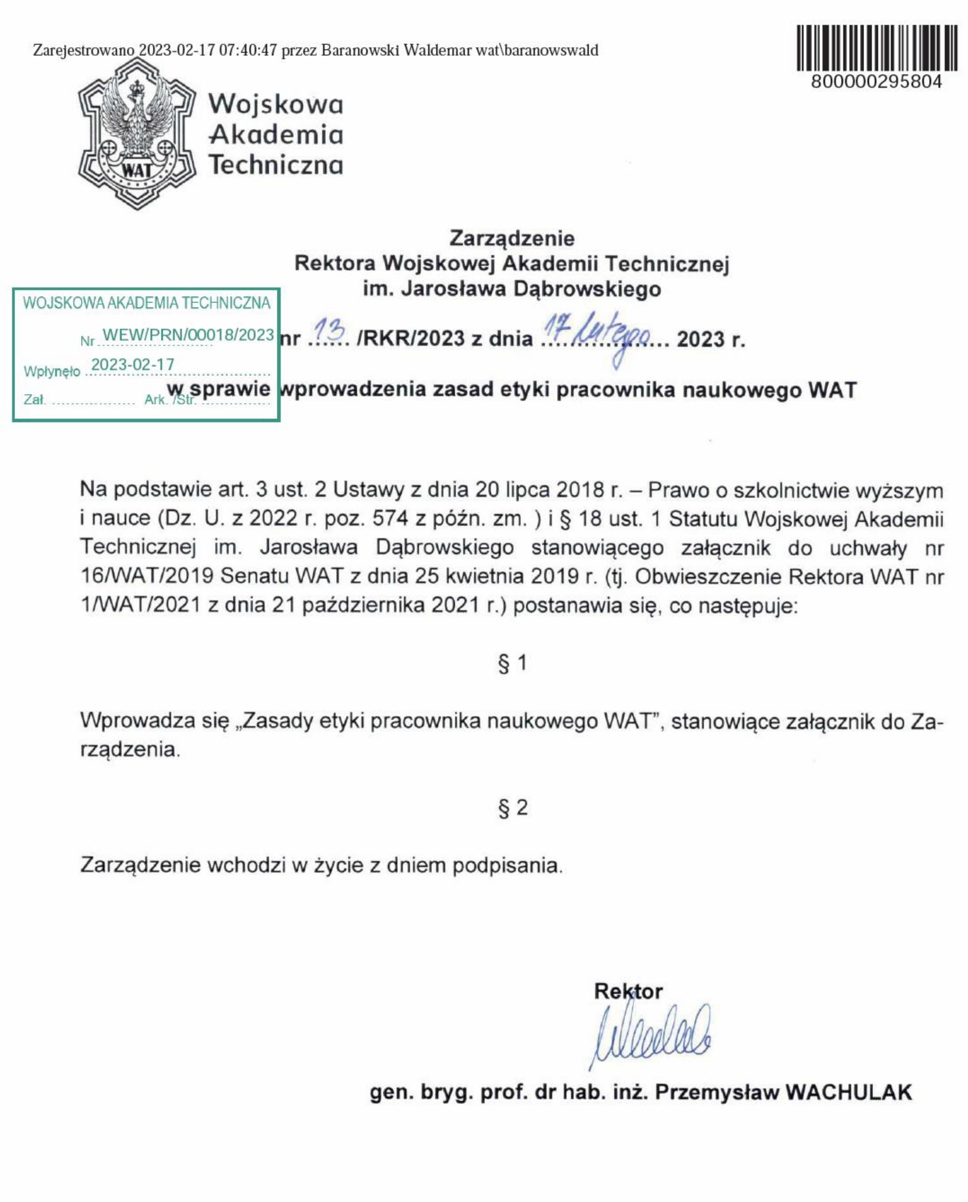
Lecture since 2nd semester 2022/2023

6	NAS wykład 06	**NAS-06**	FOSREM – idea
7	NAS wykład 07	**NAS-07**	FOSREM – realization
Nietelekomunikacyjne Zastosowania Światłowodów – szkoła doktorska			
1	NZS wykład 01	**NZS-01**	Terminologia czujników światłowodowych
2	NZS wykład 02	**NZS-02**	Interferometry światłowodowe – podstawy
3	NZS wykład 03	**NZS-03**	Interferometry światłowodowe – obróbka optyczna
4	NZS wykład 04	**NZS-04**	Interferometry światłowodowe – obróbka elektroniczna
5	NZS wykład 05	**NZS-05**	Optyczne przetworniki fazowe
6	NZS wykład 06	**NZS-06**	Zasady zwielokrotnienia czujników punktowych
7	NZS wykład 07	**NZS-07**	Czujniki o rozłożonym polu detekcji
8	NZS wykład 08	**NZS-08**	Żyroskop światłowodowy
9	NZS wykład 08	**NZS-09**	Światłowodowy sejsmometr rotacyjny
10	NZS wykład 09	**NZS-10**	FOSREM realizacja
Metodologia Prowadzenia Badań Naukowych – szkoła doktorska			
0	Szkoła doktorska	**MBN0**	Początek XX w. jako relatywistyczny przełom w fizyce
1	Szkoła doktorska	**MBN1**	Formalna strona badań naukowych
2	Szkoła doktorska	**MBN2**	Wiarygodność naukowa
3	Szkoła doktorska	**MBN3**	Artykuł naukowy
4	Szkoła doktorska	**MBN4**	Upowszechnianie wyników badań
5	Szkoła doktorska	**MBN5**	Prezentacja naukowa

Etyka w nauce



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Zarządzenie
Rektora Wojskowej Akademii Technicznej
im. Jarosława Dąbrowskiego

nr 13 /RKR/2023 z dnia 17 lutego 2023 r.

w sprawie wprowadzenia zasad etyki pracownika naukowego WAT

Na podstawie art. 3 ust. 2 Ustawy z dnia 20 lipca 2018 r. – Prawo o szkolnictwie wyższym i nauce (Dz. U. z 2022 r. poz. 574 z późn. zm.) i § 18 ust. 1 Statutu Wojskowej Akademii Technicznej im. Jarosława Dąbrowskiego stanowiącego załącznik do uchwały nr 16/WAT/2019 Senatu WAT z dnia 25 kwietnia 2019 r. (tj. Obwieszczenie Rektora WAT nr 1/WAT/2021 z dnia 21 października 2021 r.) postanawia się, co następuje:

§ 1

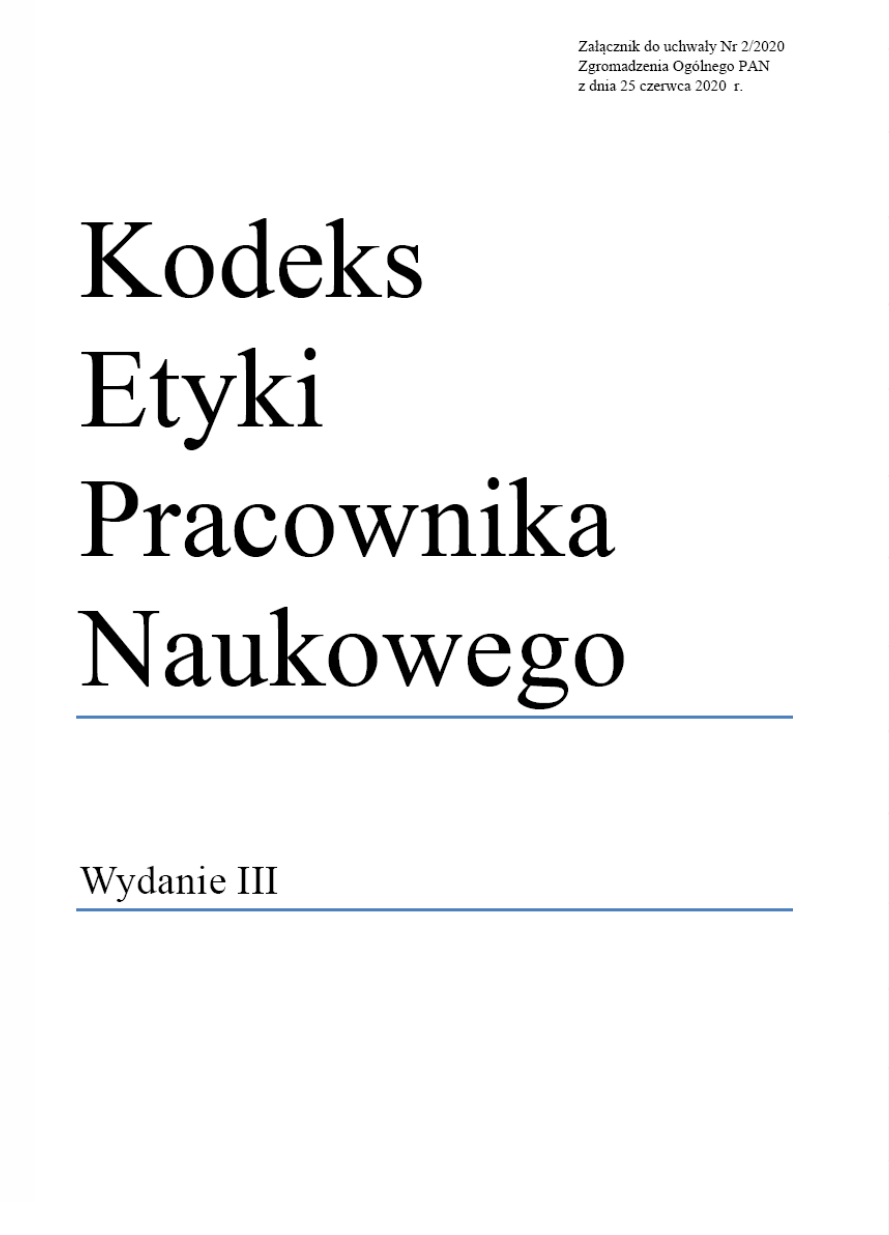
Wprowadza się „Zasady etyki pracownika naukowego WAT”, stanowiące załącznik do Zarządzenia.

§ 2

Zarządzenie wchodzi w życie z dniem podpisania.

Rektor

gen. bryg. prof. dr hab. inż. Przemysław WACHULAK

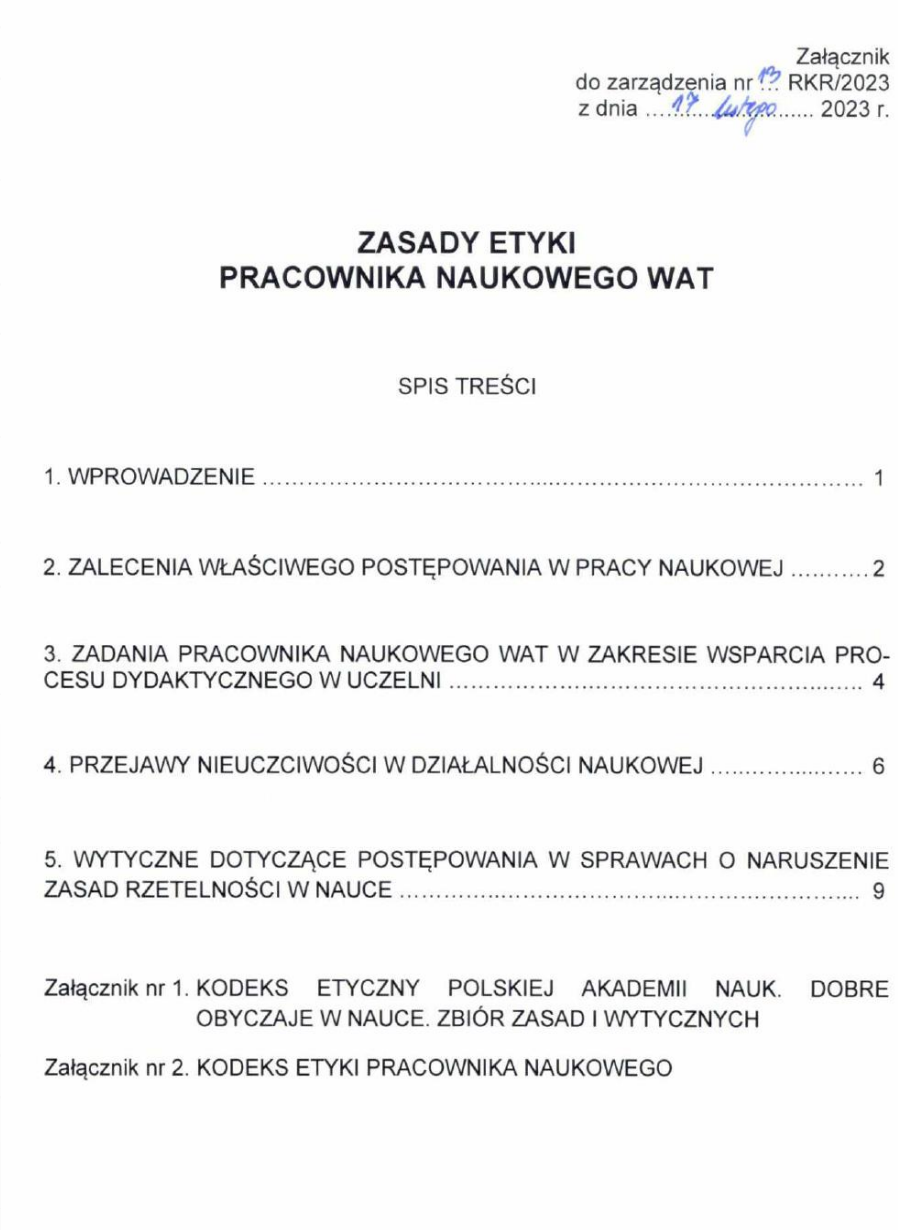


Załącznik do uchwały Nr 2/2020
Zgromadzenia Ogólnego PAN
z dnia 25 czerwca 2020 r.

Kodeks
Etyki
Pracownika
Naukowego

Wydanie III

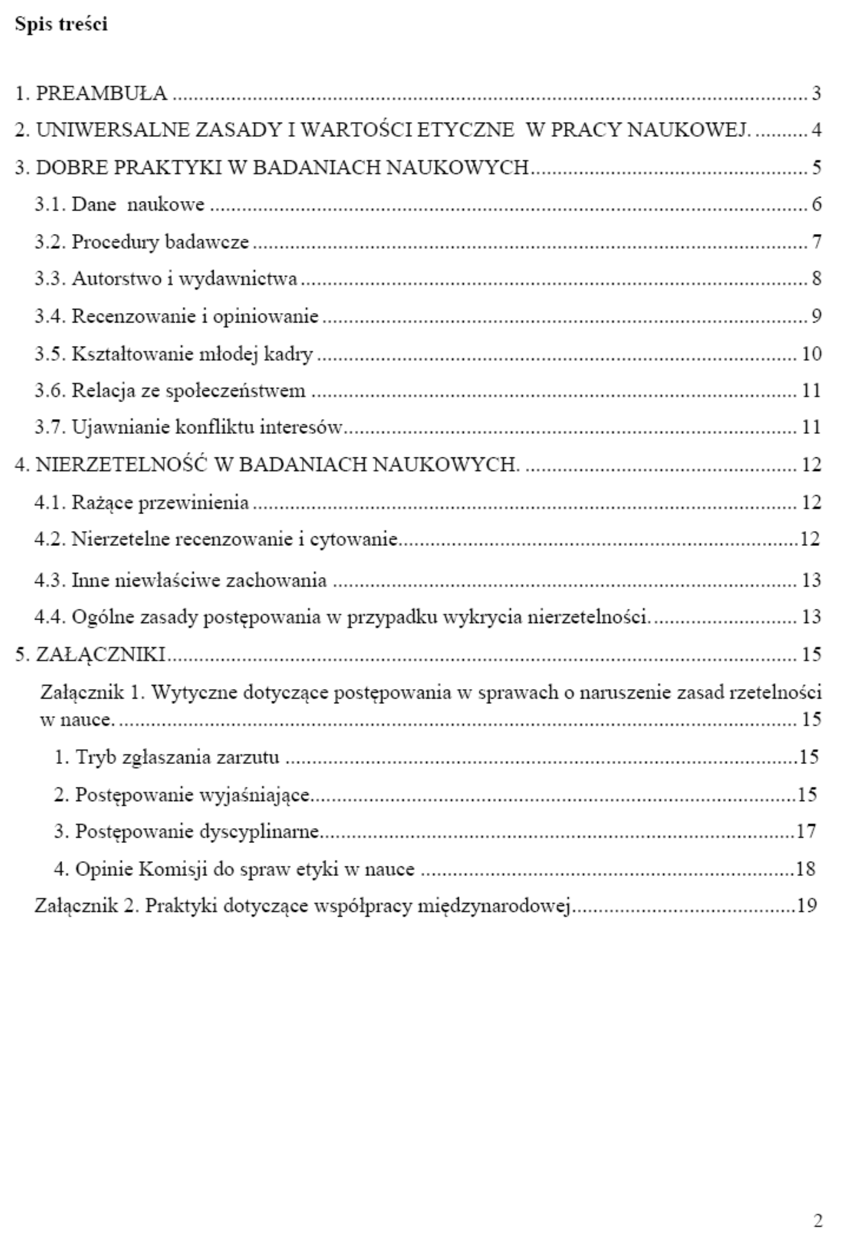
Etyka w nauce



Załącznik
do zarządzenia nr 13 RKR/2023
z dnia 17 lutego 2023 r.

ZASADY ETYKI PRACOWNIKA NAUKOWEGO WAT

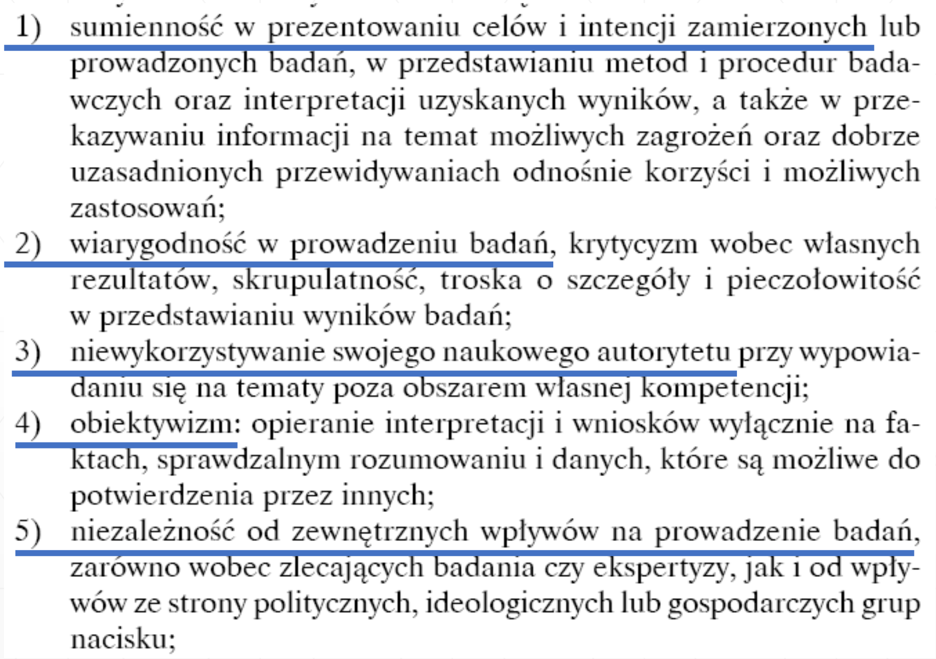
SPIS TREŚCI



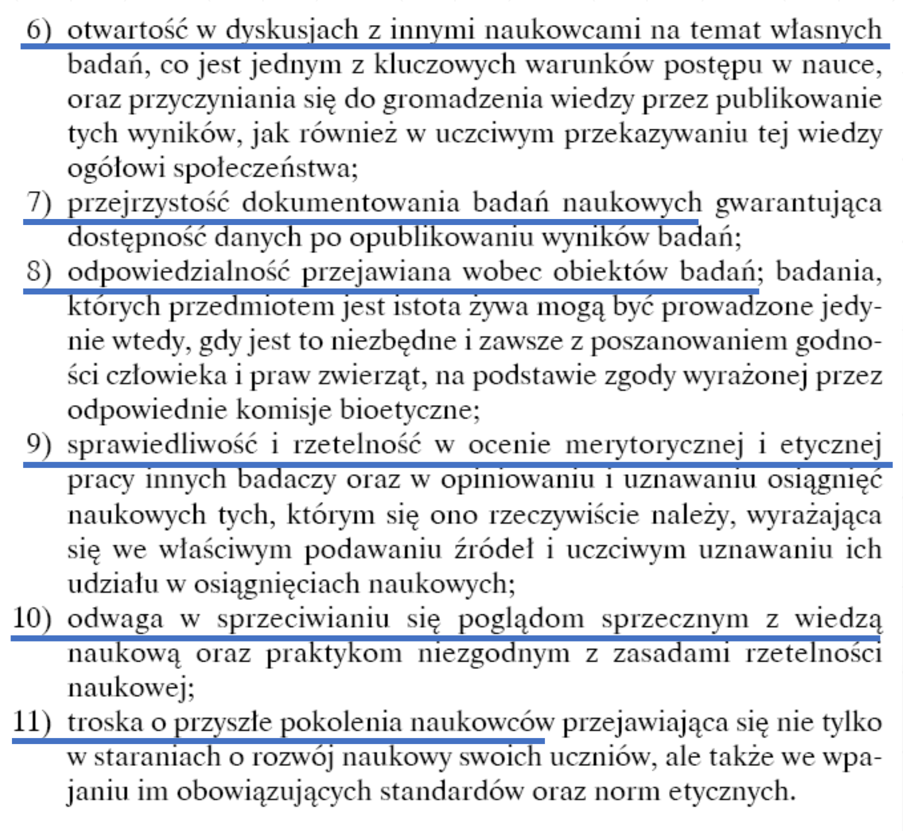
Spis treści

Uniwersalne zasady i wartości etyczne w pracy naukowej

Podstawowe, uniwersalne zasady i wartości etyczne, na których opiera się integralność i wiarygodność nauki odnoszą się do przedstawicieli wszystkich, bez wyjątku, dyscyplin naukowych. Ich przestrzegania należy wymagać od naukowców, od instytucji, w których prowadzą oni badania, a także od tych, które finansują badania i zajmują się organizacją życia naukowego, zarówno w ich wzajemnych relacjach jak i w kontaktach ze światem zewnętrznym.



1) sumienność w prezentowaniu celów i intencji zamierzonych lub prowadzonych badań, w przedstawianiu metod i procedur badawczych oraz interpretacji uzyskanych wyników, a także w przekazywaniu informacji na temat możliwych zagrożeń oraz dobrze uzasadnionych przewidywaniach odnośnie korzyści i możliwych zastosowań;
2) wiarygodność w prowadzeniu badań, krytycyzm wobec własnych rezultatów, skrupulatność, troska o szczegóły i pieczołowitość w przedstawianiu wyników badań;
3) niewykorzystywanie swojego naukowego autorytetu przy wypowiadaniu się na tematy poza obszarem własnej kompetencji;
4) obiektywizm: opieranie interpretacji i wniosków wyłącznie na faktach, sprawdzalnym rozumowaniu i danych, które są możliwe do potwierdzenia przez innych;
5) niezależność od zewnętrznych wpływów na prowadzenie badań, zarówno wobec zlecających badania czy ekspertyzy, jak i od wpływów ze strony politycznych, ideologicznych lub gospodarczych grup nacisku;



6) otwartość w dyskusjach z innymi naukowcami na temat własnych badań, co jest jednym z kluczowych warunków postępu w nauce, oraz przyczyniania się do gromadzenia wiedzy przez publikowanie tych wyników, jak również w uczciwym przekazywaniu tej wiedzy ogółowi społeczeństwa;
7) przejrzystość dokumentowania badań naukowych gwarantująca dostępność danych po opublikowaniu wyników badań;
8) odpowiedzialność przejawiana wobec obiektów badań; badania, których przedmiotem jest istota żywa mogą być prowadzone jedynie wtedy, gdy jest to niezbędne i zawsze z poszanowaniem godności człowieka i praw zwierząt, na podstawie zgody wyrażonej przez odpowiednie komisje bioetyczne;
9) sprawiedliwość i rzetelność w ocenie merytorycznej i etycznej pracy innych badaczy oraz w opiniowaniu i uznawaniu osiągnięć naukowych tych, którym się ono rzeczywiście należy, wyrażająca się we właściwym podawaniu źródeł i uczciwym uznawaniu ich udziału w osiągnięciach naukowych;
10) odwaga w sprzeciwianiu się poglądom sprzecznym z wiedzą naukową oraz praktykom niezgodnym z zasadami rzetelności naukowej;
11) troska o przyszłe pokolenia naukowców przejawiająca się nie tylko w staraniach o rozwój naukowy swoich uczniów, ale także we wpajaniu im obowiązujących standardów oraz norm etycznych.

Dobre praktyki w badaniach naukowych

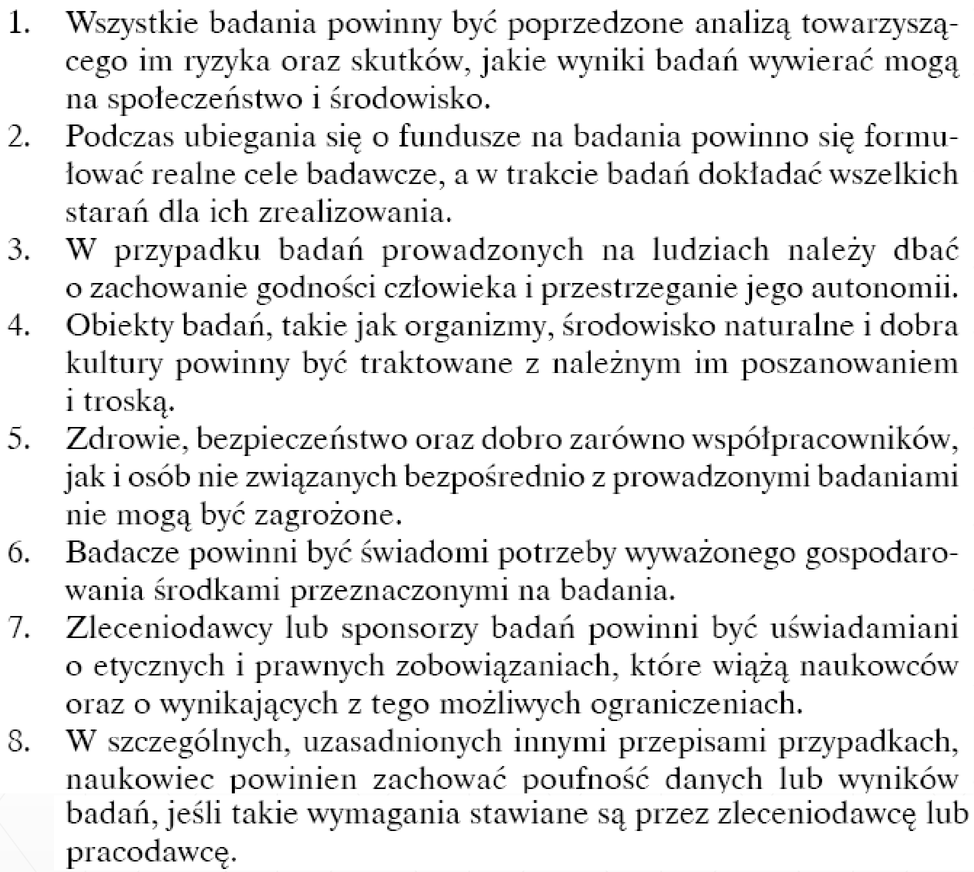
Określenie to obejmuje szczegółowe, powszechnie zrozumiałe i możliwe do wprowadzenia w poszczególnych jednostkach naukowych reguły rzetelnego postępowania odnoszące się do prowadzenia, prezentowania i oceniania badań naukowych. Powinno to dotyczyć następujących obszarów działań:

- Postępowanie z danymi naukowymi,
- Procedury badawcze,
- Autorstwo oraz publikowanie wyników badań,
- Recenzowanie i opiniowanie,
- Formowanie młodej kadry,
- Relacje ze społeczeństwem,
- Unikanie konfliktu interesów.

Postępowanie z danymi naukowymi,

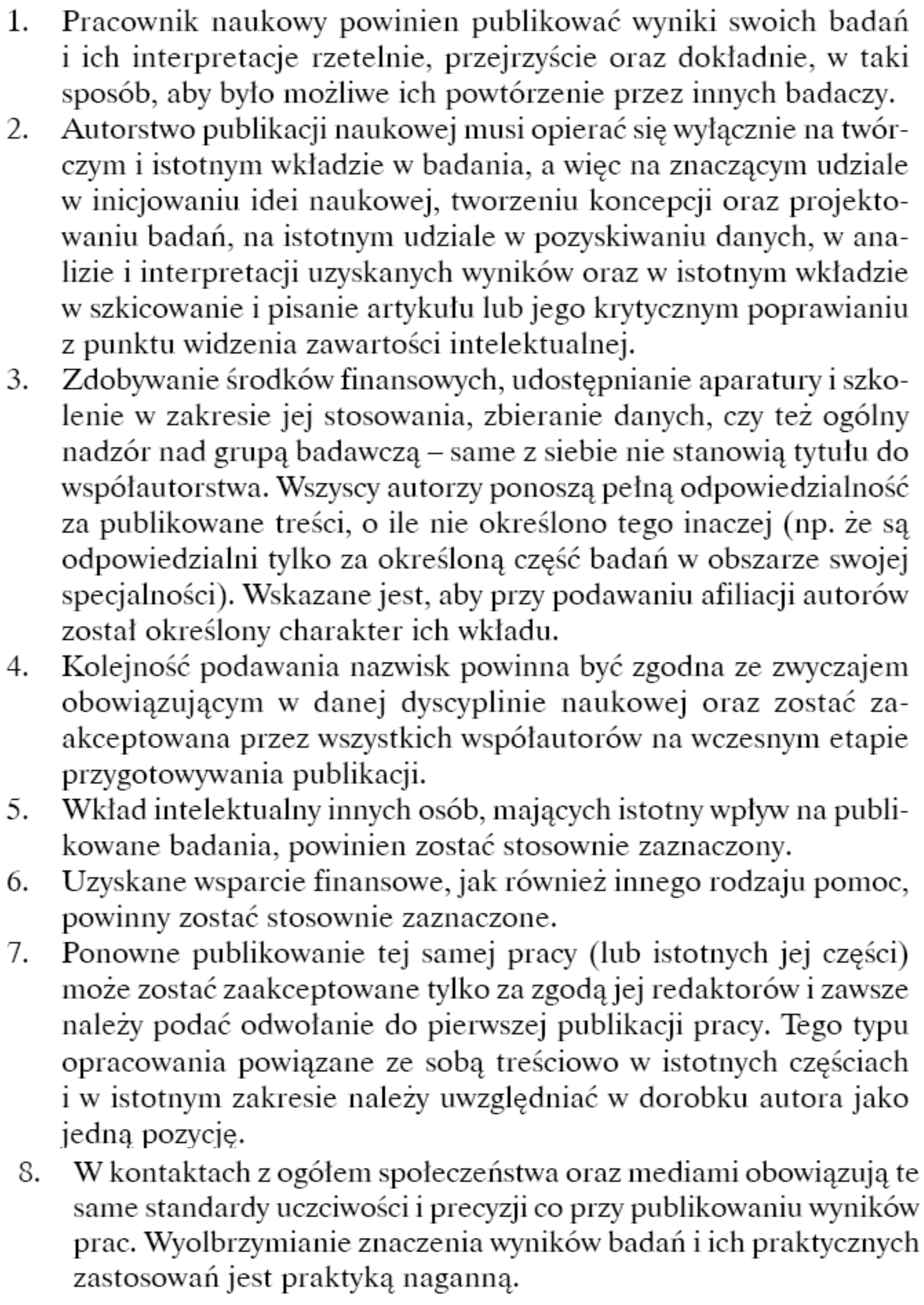
Wszystkie oryginalne dane źródłowe, na których opierają się publikacje (często próbki czy materiały pochodzące z prowadzonych badań) powinny być skrupulatnie udokumentowane i bezpiecznie archiwizowane w sposób uniemożliwiający manipulowanie nimi i zapewniający po opublikowaniu tych badań ich dostępność przez okres właściwy dla danej dyscypliny

Procedury badawcze



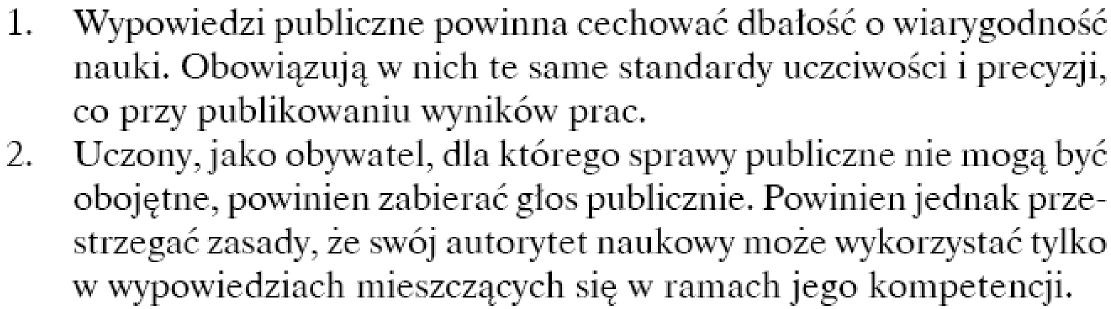
1. Wszystkie badania powinny być poprzedzone analizą towarzyszącego im ryzyka oraz skutków, jakie wyniki badań wywierać mogą na społeczeństwo i środowisko.
2. Podczas ubiegania się o fundusze na badania powinno się formułować realne cele badawcze, a w trakcie badań dokładać wszelkich starań dla ich zrealizowania.
3. W przypadku badań prowadzonych na ludziach należy dbać o zachowanie godności człowieka i przestrzeganie jego autonomii.
4. Obiekty badań, takie jak organizmy, środowisko naturalne i dobra kultury powinny być traktowane z należnym im poszanowaniem i troską.
5. Zdrowie, bezpieczeństwo oraz dobro zarówno współpracowników, jak i osób nie związanych bezpośrednio z prowadzonymi badaniami nie mogą być zagrożone.
6. Badacze powinni być świadomi potrzeby wyważonego gospodarowania środkami przeznaczonymi na badania.
7. Zleceniodawcy lub sponsorzy badań powinni być uświadamiani o etycznych i prawnych zobowiązaniach, które wiążą naukowców oraz o wynikających z tego możliwych ograniczeniach.
8. W szczególnych, uzasadnionych innymi przepisami przypadkach, naukowiec powinien zachować poufność danych lub wyników badań, jeśli takie wymagania stawiane są przez zleceniodawcę lub pracodawcę.

Praktyki autorskie i wydawnicze



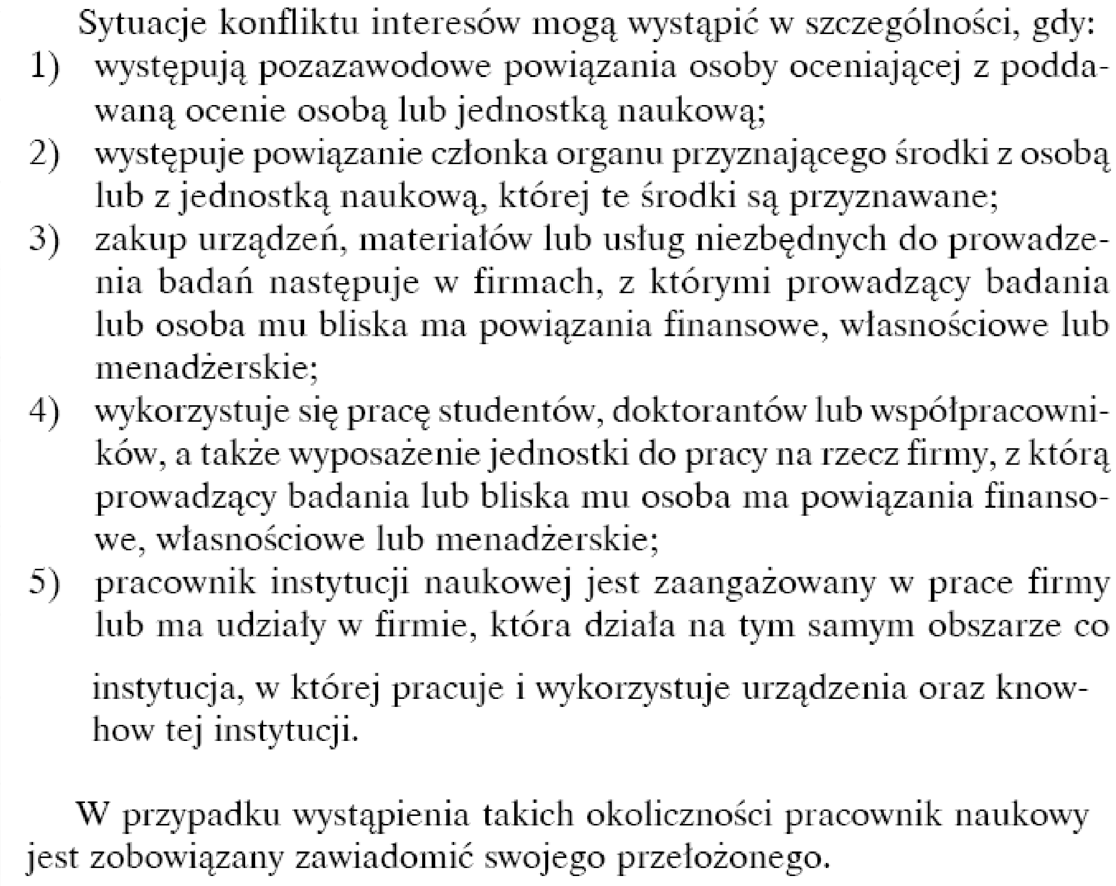
1. Pracownik naukowy powinien publikować wyniki swoich badań i ich interpretacje rzetelnie, przejrzyście oraz dokładnie, w taki sposób, aby było możliwe ich powtórzenie przez innych badaczy.
2. Autorstwo publikacji naukowej musi opierać się wyłącznie na twórczym i istotnym wkładzie w badania, a więc na znaczącym udziale w inicjowaniu idei naukowej, tworzeniu koncepcji oraz projektowaniu badań, na istotnym udziale w pozyskiwaniu danych, w analizie i interpretacji uzyskanych wyników oraz w istotnym wkładzie w szkicowanie i pisanie artykułu lub jego krytycznym poprawianiu z punktu widzenia zawartości intelektualnej.
3. Zdobywanie środków finansowych, udostępnianie aparatury i szkolenie w zakresie jej stosowania, zbieranie danych, czy też ogólny nadzór nad grupą badawczą – same z siebie nie stanowią tytułu do współautorstwa. Wszyscy autorzy ponoszą pełną odpowiedzialność za publikowane treści, o ile nie określono tego inaczej (np. że są odpowiedzialni tylko za określoną część badań w obszarze swojej specjalności). Wskazane jest, aby przy podawaniu afiliacji autorów został określony charakter ich wkładu.
4. Kolejność podawania nazwisk powinna być zgodna ze zwyczajem obowiązującym w danej dyscyplinie naukowej oraz zostać zaakceptowana przez wszystkich współautorów na wczesnym etapie przygotowywania publikacji.
5. Wkład intelektualny innych osób, mających istotny wpływ na publikowane badania, powinien zostać stosownie zaznaczony.
6. Uzyskane wsparcie finansowe, jak również innego rodzaju pomoc, powinny zostać stosownie zaznaczone.
7. Ponowne publikowanie tej samej pracy (lub istotnych jej części) może zostać zaakceptowane tylko za zgodą jej redaktorów i zawsze należy podać odwołanie do pierwszej publikacji pracy. Tego typu opracowania powiązane ze sobą treściowo w istotnych częściach i w istotnym zakresie należy uwzględniać w dorobku autora jako jedną pozycję.
8. W kontaktach z ogółem społeczeństwa oraz mediami obowiązują te same standardy uczciwości i precyzji co przy publikowaniu wyników prac. Wyolbrzymianie znaczenia wyników badań i ich praktycznych zastosowań jest praktyką naganną.

Relacje ze społeczeństwem



1. Wypowiedzi publiczne powinna cechować dbałość o wiarygodność nauki. Obowiązują w nich te same standardy uczciwości i precyzji, co przy publikowaniu wyników prac.
2. Uczony, jako obywatel, dla którego sprawy publiczne nie mogą być obojętne, powinien zabierać głos publicznie. Powinien jednak przestrzegać zasady, że swój autorytet naukowy może wykorzystać tylko w wypowiedziach mieszczących się w ramach jego kompetencji.

Unikanie konfliktu interesów



Sytuacje konfliktu interesów mogą wystąpić w szczególności, gdy:

1) występują pozazawodowe powiązania osoby oceniającej z poddawaną ocenie osobą lub jednostką naukową;
2) występuje powiązanie członka organu przyznającego środki z osobą lub z jednostką naukową, której te środki są przyznawane;
3) zakup urządzeń, materiałów lub usług niezbędnych do prowadzenia badań następuje w firmach, z którymi prowadzący badania lub osoba mu bliska ma powiązania finansowe, własnościowe lub menadżerskie;
4) wykorzystuje się pracę studentów, doktorantów lub współpracowników, a także wyposażenie jednostki do pracy na rzecz firmy, z którą prowadzący badania lub bliska mu osoba ma powiązania finansowe, własnościowe lub menadżerskie;
5) pracownik instytucji naukowej jest zaangażowany w prace firmy lub ma udziały w firmie, która działa na tym samym obszarze co instytucja, w której pracuje i wykorzystuje urządzenia oraz know-how tej instytucji.

W przypadku wystąpienia takich okoliczności pracownik naukowy jest zobowiązany zawiadomić swojego przełożonego.

Nierzetelność w badaniach naukowych

Do najpoważniejszych przewinień, szczególnie godzących w etos badań naukowych, należą fabrykowanie i fałszowanie wyników badań, które stanowią rażące naruszenie podstawowych zasad uprawiania nauki, a także popełnianie plagiatów.

1. **Fabrykowanie** wyników polega na zmyślaniu wyników badań i przedstawianiu ich jako prawdziwych,
2. **Fałszowanie** polega na zmienianiu lub pomijaniu niewygodnych danych, przez co wyniki badań nie zostają prawdziwie zaprezentowane,
3. **Popełnianie plagiatów** polega na przywłaszczaniu cudzych idei, wyników badań lub słów bez poprawnego podania źródła, co stanowi naruszenie praw własności intelektualnej.
4. **Sporządzanie nierzetelnych recenzji** rozpraw doktorskich, habilitacyjnych, wniosków o tytuł i wszelkich wniosków o zatrudnianie w instytucjach naukowych, a także recenzji projektów badawczych oraz uchylanie się od wyrażenia opinii lub jej odmowa, w przypadku gdy ocena, zdaniem opiniującego, powinna być negatywna – jest również rażącym przewinieniem.

Popełnienie powyższych przewinień może przyczynić się do dyskwalifikacji ich sprawcy jako naukowca. Ich ujawnienie musi więc bezwzględnie prowadzić do wszczęcia postępowania dyscyplinarnego.

Inne niewłaściwe zachowania

- Wykorzystaniu przy prowadzeniu badań naukowych wkładu innych osób bez odpowiedniej rekompensaty finansowej lub bez zaznaczenia tego wkładu w publikacji,
- Zezwolenie na współautorstwo publikacji osób, które nie wniosły wystarczającego wkładu intelektualnego w ich powstanie,
- Przyzwolenie na pozorność badań naukowych niemających nic wspólnego z rzetelnym procesem poznawczym,
- Wszelkie formy prześladowań i dyskryminacji, niewłaściwe wykorzystanie funduszów na badania oraz nieujawnianie konfliktu interesów.

sensors

MDPI

Review

Review of the Usefulness of Various Rotational Seismometers with Laboratory Results of Fibre-Optic Ones Tested for Engineering Applications

Leszek R. Jaroszewicz [1], Anna Kurzych [1,*], Zbigniew Krajewski [1], Paweł Marć [1], Jerzy K. Kowalski [2], Piotr Bobra [3], Zbigniew Zembaty [3], Bartosz Sakowicz [4] and Robert Jankowski [5]

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Abstract: Starting with descriptions of rotational seismology, areas of interest and historical field measurements, the fundamental requirements for rotational seismometers for seismological and engineering application are formulated. On the above basis, a review of all existing rotational seismometers is presented with a description of the principles of their operation as well as possibilities to fulfill formulated requirements. This review includes mechanical, acoustical, electrochemical and optical devices and shows that the last of these types are the most promising. It is shown that optical rotational seismometer based on the ring-laser gyroscope concept is the best for seismological applications, whereas systems based on fiber-optic gyroscopes demonstrate parameters which are also required for engineering applications. Laboratory results of the Fibre-Optic System for Rotational Events & Phenomena Monitoring using a small 1-D shaking table modified to generate rotational excitations are presented. The harmonic and time-history tests demonstrate its usefulness for recording rotational motions with rates up to 0.25 rad/s.

Keywords: fibre-optic interferometric sensor; rotational seismometer; seismological investigation; strong motion seismology; earthquakes; shaking table

1. Introduction

Recently, there has been increasing interest in rotational ground motion measurements. It is believed that rotational signals may contain additional valuable information for studying wave propagation; in addition, rotational ground motion may be important in the excitations of certain engineering structures. According to the introduction to a special issue of the Bulletin of the Seismological Society of America, [1] rotational seismology has become an emerging field for the study of all aspects of rotational ground motion induced by earthquakes, explosions, and ambient vibrations. This domain has attracted the attention of researchers from a wide range of geophysical disciplines, including broadband seismology, strong-motion seismology [2], earthquake engineering including seismic behaviour of irregular and complex civil structures [3,4], earthquake physics [5,6], seismic instrumentation [7], seismic hazards [8], seismotectonics [9], geodesy [10], and from physicists using Earth-based observatories for detecting gravitational waves generated by astronomical sources [11,12].

Sensors **2016**, *16*, 2161; doi:10.3390/s16122161 www.mdpi.com/journal/sensors

The likely rotational effects of an earthquake wave, together with the rotations caused by a soil-structure interaction, have been observed for centuries; this is shown in the summary by Kozák [13], in which an image of a rotated obelisk after the 1783 Calabria earthquake is cited as the first illustration of this phenomena. The physical description of earthquake rotational effects is based on two classes of rotational seismic models [14,15]. The first class includes historic models, as defined by Mallet [16] in the mid-nineteenth century, and based on the rotation of bodies with respect to their underlying structures. The second class is derived from recent progress in theoretical studies on micromorphic and asymmetric theories of continuum mechanics as well as in nonlinear physics; an overview of these can be found in monographs by Teisseyre et al. [5,6]. In this field, both theoretical [17,18] and experimental evidence [19] regarding the existence of rotational seismic waves should be considered.

Similarly, recent progress in the structural heath monitoring of civil engineering structures has prompted scientists to investigate the existence of rotations in structural responses to any type of excitations. However, the primary interests of researchers of rotational seismic engineering are associated mainly with formulating additional seismic loads on structures in terms of the rotational seismic excitations. While building responses to translational motion has been thoroughly investigated and implemented into design codes of practice, the study of building response to rotational motions is a relatively new field [20]. This is because the engineering importance of the rotational components of strong seismic ground motion was noted much later than the translational seismic effects [21,22]. From an engineering standpoint, this rotation may be responsible for damage in high-rise buildings [23] and in those structures where the soil-structure interaction effects are expected to be significant [24,25].

Early attempts towards practical studies measuring rotational ground motions can be found in pioneering works from several countries. More than a century ago, Galitzin [26] suggested using two identical pendulums installed on different sides of the same rotational axis for separate measurements of rotational and translational motion. This idea was later used in an instrument designed for the registration of strong ground motion [27] as well as in a system of azimuthal arrays of rotational seismographs for rock bursts in a nearby mine [28]. Another example of an early attempt to measure rotation was the construction of a gyroscopic seismometer which was used to measure a static displacement of $<10^{-3}$ m and a tilt of $<0.5 \times 10^{-6}$ rad at La Jolla, California, during the Borrego Mountain earthquake on 9 April 1968 (magnitude 6.5) [29]. Early efforts also included studies of explosions using seismological sensors to directly measure point rotations after nuclear explosions [30], as well as commercial rotational sensors based on microelectro-mechanical systems (MEMS) for identifying significant near-field rotational motions from a one-kiloton explosion [31]. Finally, it should be noted that rotations of and strains in the ground in the responses of structures have been indirectly deduced from accelerometer arrays using methods valid for seismic waves with wavelengths longer than the distances between sensors [32–39].

In Section 2 of this paper, we formulate the fundamental requirements for a rotational seismometer regarding the two main areas of interest described above, i.e., for seismological and engineering applications. The subsequent two sections contain descriptions of all the main types of rotational seismometers with a discussion of their principles of operation and a comparison of their fundamental parameters. These devices can be divided into two groups of sensors: rotational sensors based on classical seismometers which detect rotation in an indirect way, such as mechanical or acoustical types, described in Section 3, and rotational sensors which detect rotation directly, such as the electrochemical, mechanical and optical types (Section 4). These descriptions include a discussion of how far the requirements formulated in Section 2 for seismological and engineering areas of application are fulfilled, and show that the optical type of rotational seismometer, and particularly the type based on a fibre-optic gyroscope (FOG), is the most promising device for future research and application in rotational seismology. On the basis of this conclusion, Section 5 presents the results of a laboratory implementations of the loop interferometer for appropriate detection of distances of this magnitude or lower.

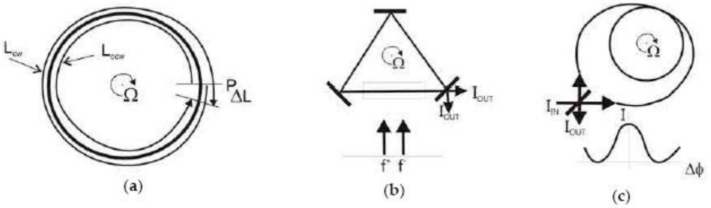

Figure 7. The Sagnac effect in a circular ring interferometer rotating with respect to an inertial frame of reference: (**a**) interferometric systems for its detection; (**b**) active method in the ring-laser approach; (**c**) passive method in a fibre-optic interferometer approach. Notation: L_{cw}, L_{ccw}—distances in clockwise and counterclockwise directions; I_{IN}, I_{UOT}—intensities of input and output beams respectively [77].

The ring-laser set-up for the measurement of ΔL is the loop interferometer, which includes an optical amplifier within the resonator [78]. This type of amplifier enables laser oscillation at f^q along the (q = +) and (q = −) directions within the resonator (lower part of Figure 7b). In the presence of rotation Ω, the frequency difference Δf is given by:

$$\Delta f = f^{+} - f^{-} = \frac{4A}{\lambda P}(\mathbf{n}, \Omega), \tag{6}$$

where λ is the optical wavelength of the laser oscillator, $\mathbf{n}$ is the normal vector to the laser beam plane and P is the perimeter enclosed by the beam path. The ring-laser approach using a He-Ne amplifier [79] was the first successful ring-laser gyroscope (RLG) and is now being used in a number of civilian and military navigation systems. The implementation of this type of system for seismological research has been proposed in various systems including the C-II [80] and GEO ring-lasers [81] in Christchurch, New Zealand, and the G-ring laser in Wettzell, Germany [82] (Figure 8). These have two major advantages for applications in seismic studies compared to the other seismometers discussed above, since they measure absolute rotation with respect to the local universe, and they do not depend on accelerated masses. In particular, this last property ensures an extremely wide dynamic range of operation, from a few 10^{-6} Hz for geophysical signals up to more than 10 Hz, as obtained from regional earthquakes [83]. Since the G-ring laser is at present the system with the best signal-to-noise performance, its parameters are included in Table 3 for comparison with other optical rotational seismometers.

(**a**) (**b**) (**c**)

Figure 8. The ring laser rotational seismometer [84]: (**a**) C-II, horizontally installed; (**b**) G, horizontally installed; (**c**) GEO, vertically installed.

Arising from the above fundamental constraint, are devices which use light for their operation. The von Laue-Sagnac effect is currently a useful basis as a physical principle for construction of the rotational seismometer, as one can see from the parameters presented by existing devices. The main advantage of this type of sensor is its complete insensitivity to linear motion and its direct measurement of rotational speed.

The development of the optical gyroscope nearly half a century ago offers an excellent technological and technical solution for the construction of an optical rotational seismometer. Despite the incredible sensitivity of ring-laser rotational seismometers, their dimensions, power consumption, and environment instability mean that such devices are best suited for stationary research into fundamental geophysical phenomena.

The review presented here shows that fibre-optic rotational seismometers are the most attractive option, since their parameters can meet all the requirements of the various areas of interest within rotational seismology. Unfortunately, as can be observed from their limited applications, the direct application of the commercially available FOGs does not fulfil these requirements, since FOGs are optimised for monitoring angle changes rather than rotation rate. In view of this, new types of devices are required, and BlueSeis-3A and FOSREM are the first of these. FOSREM, presented in this paper, fulfils all the technical requirements for rotational motion detection, in both seismological observatories and in engineering constructions. It guarantees a wide range of the detected signal amplitude up to 10 rad/s, as well as a wide range of frequencies, from DC up to 328.12 Hz. Experimental investigation indicates that FOSREM has an accuracy in the range 3×10^{-8} to 1.6×10^{-6} rad/s in the abovementioned frequency bandpass, and in practice detects rotation with an amplitude of 0.25 rad/s. It is a remotely controlled sensor which is portable and works autonomously. Additionally, the use of cloud system by FOSREM allows the integration of dozen of sensors in a worldwide network, each transferring data to the central cloud-based system. The data can be viewed and analysed from anywhere in the world via the internet. The authors believe that the further application of FOSREM in the investigation of rotational seismology effects will contribute to the provision of interesting and useful data.

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Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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PS From 12-16 December I will be attending the AGU conference

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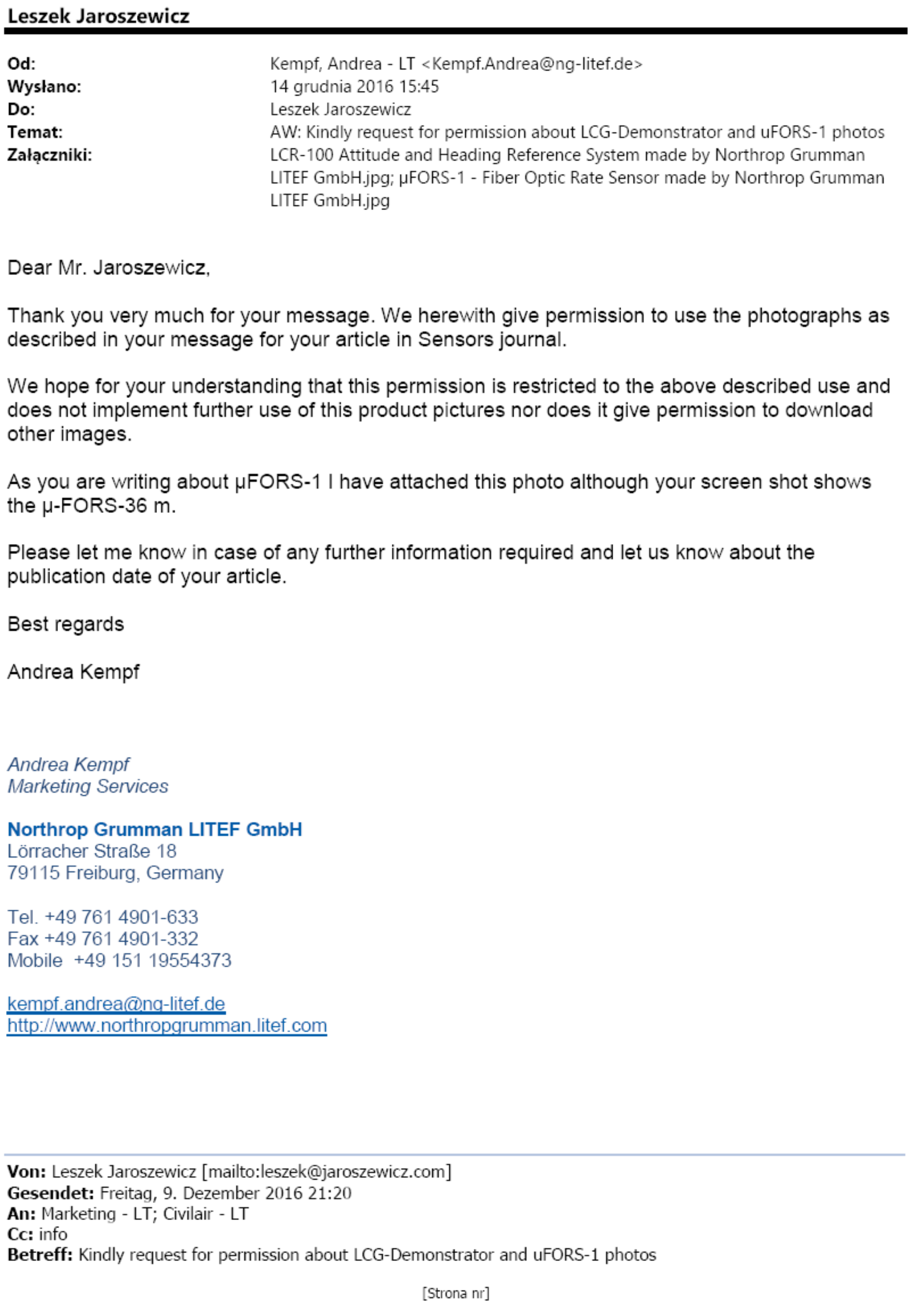

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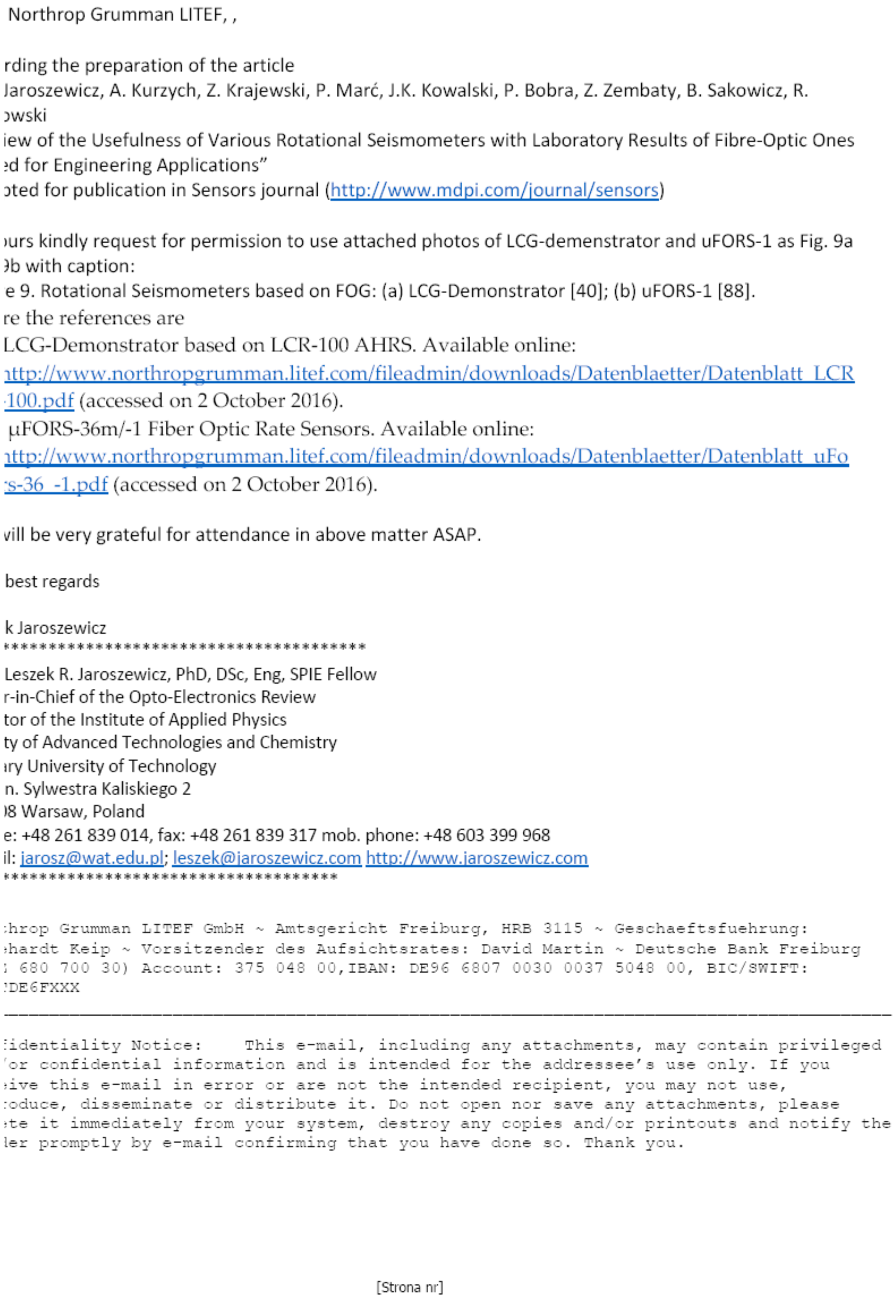

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8

Mueller Matrices for Reflection and Transmission

8.1 INTRODUCTION

In previous chapters the Mueller matrices were introduced in a very formal manner. The Mueller matrices were derived for a polarizer, retarder, and rotator in terms of their fundamental behavior; their relation to actual physical problems was not emphasized. In this chapter we apply the Mueller matrix formulation to a number of problems of great interest and importance in the physics of polarized light. One of the major reasons for discussing the Stokes parameters and the Mueller matrices in these earlier chapters is that they provide us with an excellent tool for treating many physical problems in a much simpler way than is usually done in optical textbooks. In fact, one quickly discovers that many of these problems are sufficiently complex that they preclude any but the simplest to be considered without the application of the Stokes parameters and the Mueller matrix formalism.

One of the earliest problems encountered in the study of optics is the behavior of light that is reflected and transmitted at an air–glass interface. Around 1808, E. Malus discovered, quite by accident, that unpolarized light became polarized when it was reflected from glass. Further investigations were made shortly afterward by D. Brewster, who was led to enunciate his famous law relating the polarization of the reflected light and the refractive index of the glass to the incident angle now known as the Brewster angle; the practical importance of this discovery was immediately recognized by Brewster's contemporaries. The study of the interaction of light with material media and its reflection and transmission as well as its polarization is a topic of great importance.

The interaction of light beams with dielectric surfaces and its subsequent reflection and transmission is expressed mathematically by a set of equations known as Fresnel's equations for reflection and transmission. Fresnel's equations

can be derived from Maxwell's equations. We shall derive Fresnel's equations in the next Section.

In practice, if one attempts to apply Fresnel's equations to any but the simplest problems, one quickly finds that the algebraic manipulation is very involved. This complexity accounts for the omission of many important derivations in numerous textbooks. Furthermore, the cases that are treated are usually restricted to, say, incident linearly polarized light. If one is dealing with a different state of polarized light, e.g., circularly polarized or unpolarized light, one must usually begin the problem anew. We see that the Stokes parameters and the Mueller matrix are ideal to handle this task.

The problems of complexity and polarization can be readily treated by expressing Fresnel's equations in the form of Stokes vectors and Mueller matrices. This formulation of Fresnel's equations and its application to a number of interesting problems is the basic aim of the present chapter. As we shall see, both reflection and refraction (transmission) lead to Mueller matrices that correspond to polarizers for materials characterized by a real refractive index n. Furthermore, for total internal reflection (TIR) at the critical angle the Mueller matrix for refraction reduces to a null Mueller matrix, whereas the Mueller matrix for reflection becomes the Mueller matrix for a phase shifter (retarder).

The Mueller matrices for reflection and refraction are quite complicated. However, there are three angles for which the Mueller matrices reduce to very simple forms. These are for (1) normal incidence, (2) the Brewster angle, and (3) an incident angle of 45°. All three reduced matrix forms suggest interesting ways to measure the refractive index η of the dielectric material. These methods will be discussed in detail.

In practice, however, we must deal not only with a single air–dielectric interface but also with a dielectric medium of finite thickness, that is, dielectric plates. Thus, we must consider the reflection and transmission of light at multiple surfaces. In order to treat these more complicated problems, we must multiply the Mueller matrices. We quickly discover, however, that the matrix multiplication requires a considerable amount of effort because of the presence of the off-diagonal terms in the Mueller matrices. This suggests that we first transform the Mueller matrices to a diagonal representation; matrix multiplication of diagonal matrices leads to another diagonal matrix. Therefore, in the final chapters of this part of the book, we introduce the diagonalized Mueller matrices and treat the problem of transmission through a single dielectric plate and through several dielectric plates. This last problem is of particular importance, because at present it is one of the major ways to create polarized light in the infrared spectrum.

8.2 FRESNEL'S EQUATIONS FOR REFLECTION AND TRANSMISSION

In this section we derive Fresnel's equations. Although this material can be found in many texts, it is useful and instructive to reproduce it here because it is so intimately tied to the polarization of light. Understanding the behavior of both the amplitude and phase of the components of light is essential to designing polarization components or analyzing optical system performance. We start with a review of concepts from electromagnetism.

maximum. The angle at which the maximum takes place is 56.7° (this will be shown shortly) and P is 0.9998 or 1.000 to three significant places. At this particular angle incident unpolarized light becomes completely polarized on being reflected. This angle is known as the polarization or Brewster angle (written θ_{i_B}). We shall see shortly that at the Brewster angle the Mueller matrix for reflection (8-34) simplifies significantly. This discovery by Brewster is very important because it allows one not only to create completely polarized light but partially polarized light as well. This latter fact is very often overlooked. Thus, if we have a perfect unpolarized light source, we can by a single reflection obtain partially polarized light to any degree we wish. In addition to this behavior of unpolarized light an extraordinarily simple mathematical relation emerges between the Brewster angle and the refractive indices of the dielectric materials, i.e., (8-26): this relation was used to obtain the value 56.7°.

With respect to creating partially polarized light, it is of interest to determine the intensity of the reflected light. From (8-40) we see that the intensity I_R of the reflected beam is

$$I_R = \frac{1}{2}\left(\frac{\tan\theta_-}{\sin\theta_+}\right)^2 (\cos^2\theta_- + \cos^2\theta_+) \tag{8-44}$$

In Fig. 8-11 we have plotted the magnitude of the reflected intensity I_R as a function of incident angle θ_i for a dielectric (glass) with a refractive index of 1.5. Figure 8-11 shows that as the incidence angle increases, the reflected intensity increases, particularly at the larger incidence angles. This explains why when the sun is low in the sky the light reflected from the surface of water appears to be quite strong. In fact, at these "low" angles polarizing sunglasses are only partially

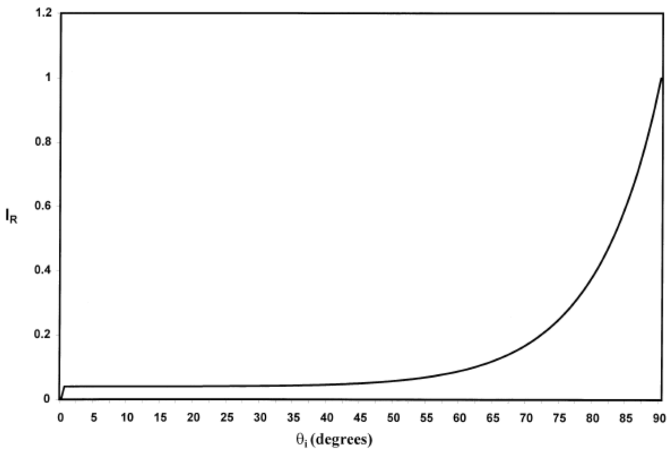

Figure 8-11 Plot of the intensity of a beam reflected by a dielectric of refractive index of 1.5. The incident beam is unpolarized.

we see that the Stokes vector of the emerging beam is

$$S = I_0 \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} \tag{8-106}$$

which is, of course, the Stokes vector of right circularly polarized light. Fresnel was the first to design and construct the rhombohedral prism which bears his name. He then used the prism to create circularly polarized light. Before Fresnel did so, *no one* had ever created circularly polarized light! This success was another triumph for his wave theory and his amplitude formulation of polarized light.

The major advantage of casting the problem of reflection and transmission at an optical interface into the formalism of the Mueller matrix calculus and the Stokes parameters is that we then have a single formulation for treating any polarization problem. In particular, very simple forms of the Mueller matrix arise at an incidence angle of 0°, the Brewster angle θ_{i_B}, an incidence angle of 45°, and TIR. However, in practice we usually deal with optical materials of finite thickness. We therefore now extend the results in this chapter toward treating the problem of reflection and transmission by dielectric plates.

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9

The Mathematics of the Mueller Matrix

9.1 INTRODUCTION

Mathematical development to better understand and describe the information contained in the Mueller matrix is given in this chapter. The experimental Mueller matrix can be a complicated function of polarization, depolarization, and noise. How do we separate the specific information we are interested in, e.g., depolarization or retardance, from the measured Mueller matrix? When does an experimental matrix represent a physically realizable polarization element and when does it not? If it does not represent a physically realizable polarization element, how do we extract that information which will give us information about the equivalent physically realizable element? These are the questions we attempt to answer in this chapter.

Two algebraic systems have been developed for the solution of polarization problems in optics, the Jones formalism and the Mueller formalism. The Jones formalism is a natural consequence of the mathematical phase and amplitude description of light. The Mueller formalism comes from experimental considerations of the intensity measurements of polarized light.

R.C. Jones developed the Jones formalism in a series of papers published in the 1940s [1–3] and reprinted in a collection of historically significant papers on polarization [4]. The Jones formalism uses Jones vectors, two element vectors that describe the polarization state of light, and Jones matrices, 2×2 matrices that describe optical elements. The vectors are complex and describe the amplitude and phase of the light, i.e.,

$$\vec{\mathbf{J}}(t) = \begin{pmatrix} \vec{\mathbf{E}}_x(t) \\ \vec{\mathbf{E}}_y(t) \end{pmatrix} \tag{9-1}$$

is a time-dependent Jones vector where $\vec{\mathbf{E}}_x$, $\vec{\mathbf{E}}_y$ are the x and y components of the electric field of light traveling along the z axis. The matrices are also complex and describe the action in both amplitude and phase of optical elements on a light beam.

The Jones matrix is of the form:

$$J = \begin{pmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{pmatrix} \tag{9-2}$$

where the elements $j_{ij} = a_{ij} + ib_{ij}$ are complex. The two elements of the Jones vector are orthogonal and typically represent the horizontal and vertical polarization states. The four elements of the Jones matrix make up the transfer function from the input to the output Jones vector. Since these elements are complex, the Jones matrix contains eight constants and has eight degrees of freedom corresponding to the eight kinds of polarization behavior. A physically realizable polarization element results from any Jones matrix, i.e., there are no physical restrictions on the values of the Jones matrix elements. The Jones formalism is discussed in more detail in Chapter 11.

The Mueller formalism, already discussed in previous chapters but reviewed here, owes its name to Hans Mueller, who built on the work of Stokes [5], Soleillet [6], and Perrin [7] to formalize polarization calculations based on intensity. This work, as Jones', was also done during the 1940s but originally appeared in a now declassified report [8] and in a course of lectures at M.I.T. in 1945–1946. As we have learned, the Mueller formalism uses the Stokes vector to represent the polarization state. The Mueller matrix is a 4×4 matrix of real numbers. There is redundancy built into the Mueller matrix, since only seven of its elements are independent if there is no depolarization in the optical system. In the most general case, the Mueller matrix can have 16 independent elements; however, not every 4×4 Mueller matrix is a physically realizable polarizing element.

For each Jones matrix, there is a corresponding Mueller matrix. On conversion to a Mueller matrix, the Jones matrix phase information is discarded. A matrix with eight pieces of information is transformed to a matrix with seven pieces of information. Transformation equations for converting Jones matrices to Mueller matrices are given in Appendix C. The Mueller matrices can also be generated from equations. The Jones matrix is related to the Mueller matrix by

$$M = A(J \otimes J^*)A^{-1} \tag{9-3}$$

where $\otimes$ denotes the Kronecker product and A is

$$A = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & -1 \\ 0 & 1 & 1 & 0 \\ 0 & i & -i & 0 \end{bmatrix} \tag{9-4}$$

The elements of the Mueller matrix can also be obtained from the relation:

$$m_{ij} = \frac{1}{2}\mathrm{Tr}(J\sigma_i J^\dagger \sigma_j) \tag{9-5}$$

where $J^\dagger$ is the Hermitian conjugate of J and the σ are the set of four 2×2 matrices that comprise the identity matrix and the Pauli matrices (see Section 9.3).

The Jones matrix cannot represent a depolarizer or scatterer. The Mueller matrix can represent depolarizers and scatterers (see, e.g., [9]). Since the Mueller matrix contains information on depolarization, the conversion of Mueller matrices to Jones matrices must discard depolarization information. There is no phase information in a Mueller matrix, and the conversion conserves seven degrees of freedom.

The Mueller formalism has two advantages for experimental work over the Jones formalism. The intensity is represented explicitly in the Mueller formalism, and scattering can be included in the calculations. The Jones formalism is easier to use and more elegant for theoretical studies.

9.2 CONSTRAINTS ON THE MUELLER MATRIX

The issue of constraints on the Mueller matrix has been investigated by a number of researchers, e.g., [10–15]. The fundamental requirement that Mueller matrices must meet in order to be physically realizable is that they map physical incident Stokes vectors into physical resultant Stokes vectors. This recalls our requirement on Stokes vectors that the degree of polarization must always be less than or equal to one, i.e.,

$$P = \frac{(S_1^2 + S_2^2 + S_3^2)^{1/2}}{S_0} \leq 1 \tag{9-6}$$

A well-known constraint on the Mueller matrix is the inequality [16]:

$$\mathrm{Tr}(MM^T) = \sum_{i,j=0}^{3} m_{ij}^2 \leq 4m_{00}^2 \tag{9-7}$$

The equals sign applies for nondepolarizing systems and the inequality otherwise.

Many more constraints on Mueller matrix elements have been recorded. However, we shall not attempt to list or even to discuss them further here. The reason for this is that they may be largely irrelevant when one is making measurements with real optical systems. The measured Mueller matrices are a mixture of pure (nondepolarizing) states, depolarization, and certainly noise (optical and electronic). Is the magnitude of a particular Mueller matrix element due to diattenuation or retardance or is it really noise, or is it a mixture? If it is a mixture, what are the proportions? It is the responsibility of the experimenter to reduce noise sources as much as possible, determine the physical realizability of his Mueller matrices, and if they are not physically realizable, find the closest physically realizable Mueller matrices. A method of finding the closest physically realizable Mueller matrix and a method of decomposing nondepolarizing and depolarizing Mueller matrices are discussed in the remaining sections of this chapter. These are very important and provide useful results; however, only so much can be done to reduce noise intrusion. A study was done [17] to follow error propagation in the process of finding the best estimates, and it was found that the noise was reduced by one-third in nondepolarizing systems and reduced by one-tenth in depolarizing systems in going from the nonphysical matrix to the closest physically realizable matrix. The reduction is significant and worth doing, but no method can completely eliminate measurement noise. We will give examples in Section 9.4.

9.6 SUMMARY

We have answered the questions posed at the beginning of this chapter. With the material presented here, we now have the tools to determine whether or not a Mueller matrix is physically realizable and we have a method to bring it to the closest physically realizable matrix. We can then separate the matrix into its constituent components of diattenuation, retardance, and depolarization. We must remember, however, that noise, once introduced into the system, is impossible to remove entirely. The experimentalist must take prudent precautions to minimize the influence of errors peculiar to the system at hand.

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Polarized Light

Second Edition, Revised and Expanded

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Where there is light, there is polarized light. It is in fact difficult to find a source of light that is completely randomly polarized. As soon as light interacts with anything, whether through reflection, transmission, or scattering, there is opportunity for polarization to be induced. As pointed out in the first sentence of the Preface to the First Edition, polarization is a fundamental characteristic of the transverse wave that is light. More than ever, it is a characteristic that must be addressed in modern optical systems and applications.

Since 1993 when the first edition of this text appeared, there have been many new developments in the measurement and application of polarized light. This revised edition includes revisions and corrections of the original text and substantive new material. Most of the original figures have been redone. Chapter 8 has been expanded to include the derivation of the Fresnel equations with plots of the magnitude and phase of the reflection coefficients. Also included in Part I is a chapter with in-depth discussion of the mathematics and meaning of the Mueller matrix. In this chapter, there is a discussion of physical realizability and elimination of error sources with eigenvector techniques, and a discussion of Mueller matrix decomposition. The Lu–Chipman decomposition has shown that Mueller matrices are separable, so that a general Mueller matrix may be decomposed into a set of product matrices, each dependent on only one of the quantities of diattenuation, retardance, or depolarization. A chapter on devices and components has been added to Part III, Applications. Those interested in use or measurement of polarized light should have knowledge of available devices and components that serve as polarizers and retarders for various wavelength regions and for various conditions of achromaticity. Chapters on Stokes polarimetry and Mueller matrix polarimetry have been inserted in Part III. These polarimetric techniques are essential to an understanding of measurement of polarized light and characterization of optical elements.

The first edition was published as *Polarized Light: Fundamentals and Applications*, Edward Collett (Marcel Dekker, Inc., 1993).

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- JEZYK pisany jest diametralnie różny od MÓWIONEGO, np. dzień dobry
- Jednolita forma - zrobiłem, zrobiliśmy czy zrobiono ??? – upieram się w formie bezosobowej (artykuł w *Physical Review Letters* 24.11.1975 J.H. Hetherington, F.D.C. Willard – *Felix Domesticus* Chester Willard) .
- Użycie prawidłowego systemu jednostek [SI] i oznaczeń: akronimy, *zmienne*,
- Własność czy właściwość ??? [własność, PWN: *co ktoś posiada, czego jest właścicielem, co do kogo należy*]; [właściwość, PWN: *to, co jest charakterystyczne dla danej osoby lub rzeczy]*,
- Własności fotoelastyczne (photoelastic fenomena) → właściwości fotosprężyste,
- Współczynnik załamania światła – światło nie ma współczynnika załamania!!!, to jest z *n* – *medium refractive index,*
- Widmo o bardzo szerokim spektrum – czyli widmo o bardzo szerokim widmie

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Article

Ambient Refractive-Index Measurement with Simultaneous Temperature Monitoring Based on a Dual-Resonance Long-Period Grating Inside a Fiber Loop Mirror Structure

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Abstract: In this work, we report the experimental results on optimizing the optical structure for ambient refractive index measuring with temperature changes monitoring. The presented optical structure is based on a dual-resonance long-period grating embedded inside a fiber loop mirror, where the long-period grating acts as the head of the refractive-index sensor, whereas the section of polarization maintaining fiber in the loop mirror ensures suitable temperature sensing The optimization process was comprised of tuning the resonance and interferometric peaks by changing the state of polarization of propagating beams. Experimental results establish that the response of the proposed sensor structure is linear and goes in opposite directions: an increase in the ambient refractive index reduces the signal response, whereas a temperature increase produces an increased response. This enables us to distinguish between the signals from changes in the refractive index and temperature. Due to the filtering properties of the interferometric structure, it is possible to monitor variation in these physical parameters by observing optical power changes instead of wavelength shifts. Hence, the refractive index sensitivity has been established up to 2375.8 dB/RIU in the narrow RI range (1.333–1.341 RIU) and temperature sensitivities up to 1.1 dBm/°C in the range of 23–41 °C. The proposed sensor is dedicated to advanced chemical and biological sensor applications

Keywords: optical fiber sensor; dual-resonance long-period grating; fiber loop mirror; temperature control; refractive-index sensor

1. Introduction

Label-free monitoring of ambient refractive-index (RI) changes based on optical fiber sensing is a significant technology in biological [1], medical [2], and industrial [3] applications Among the optical fiber configurations already proposed for RI sensing are surface plasmon interference [4], fiber Bragg gratings [5], long-period gratings (LPGs) [6], Mach-Zehnder interferometers [7], and Fabry-Perot interferometers [8]. These configurations have provided ultra-high sensitivity. However, they do not exclude cross-sensitivity derived from interaction with other physical parameters. In order to obtain a pure sensor response to the measured quantity, it is essential limiting the cross-sensitivities or controls two or more parameters at the same real time. The simultaneous measurement of several parameters is a well-established technique, and it can be achieved in optical devices by differential modulation [9]

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Article

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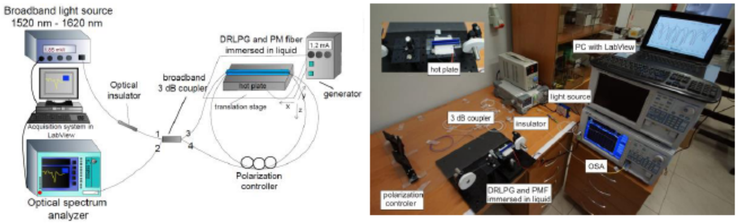

(a) (b)

Figure 1. The schematic (**a**) and general photo (**b**) of experimental setup for the ambient refractive-index (RI) and temperature measurement sensor with emphasized the polarization controller (PC) position.

When it comes to the proper investigation of the cladding mode order, in which the fundamental mode $LP_{0,1}$ is coupled in DRLPG structure, a numerical simulations should be carried out. As one can find in [35,37,38], DRLPG fabricated in conditions described above coupled the fundamental mode with $LP_{0,9}$ and $LP_{0,10}$ modes when it is immersed, respectively, in water (n = 1.3333) and liquid with a higher refractive index (more than n = 1.3808). The collaboration with the above team of authors gives the verification of the experimental information about the most probably coupling modes.

The proper wavelength characteristic is estimated by investigating PM fiber length and DRLPG wavelength influence [30,31]. The length of PM fiber was estimated in relation to the birefringence and the wavelength spacing between interference dips (16 nm) [39], which was matched to the spacing between DRLPG notches (48 nm) (Figure 2). The PC localization between the DRLPG and the PM fiber directly determines the peak amplitude and position. This implies that the PC can be used to control the behavior of the transmission spectrum and, hence, to tune the dips. For the type and length of PM fiber chosen in this test, it is possible to move the interference dips up to 9 nm and the amplitude about 11.25 dBm. For the final system adjustment, the two spectral peaks of the FLM were located in the middle of both notches of the DRLPG, as is shown in Figure 2.

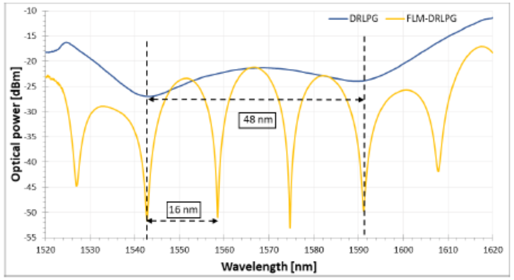

Figure 2. The transmission spectra of the dual-resonance long-period grating (DRLPG) (blue) and the DRLPG inside the fiber loop mirror (FLM) structure (yellow).

In the presented experiment, the DRLPG served as the head of the ambient RI sensor, while the PM fiber functioned additional as the temperature sensor probe. The investigated liquid was dropped into

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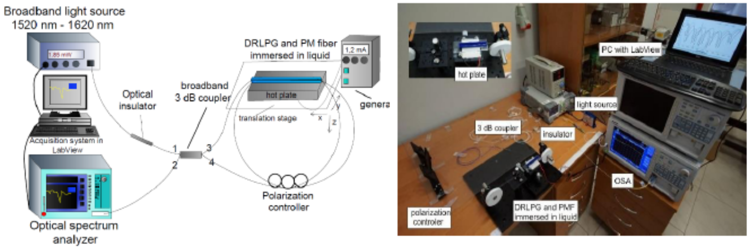

(a) (b)

Figure 1. The schematic (a) and general photo (b) of experimental setup for the ambient RI and temperature measurement sensor with emphasized the PC position.

The DRLPG used in the experiment was fabricated with standard germanium-doped Corning SMF-28 fiber. For the LPG preparation the chromium amplitude mask technique was used with a high-power KrF excimer laser (Lumonics™ Lasers: Pulse Master®-840) emitting at 248 nm with 340 nJ the peak pulse energy [35]. The 4 cm long bare fiber to be exposed to UV radiation was hydrogenated to make it photosensitive. The grating period was Λ=217 µm and the LPG was annealed at a temperature of 150°C for 90 minutes in order to stabilize its optical properties. To obtain the dual-resonance of the transmission spectrum, the LPG was tuned by etching in 10% hydrofluoric acid (HF 10%) which slightly reduce the diameter of the fiber with rate estimated using the reference samples, to be 30 nm/min. The cladding of the LPG was etched until obtaining the dual-resonance. During that process, the resonant wavelength was shifted up to DTP [36].

When it comes to the proper investigation of the cladding mode order, in which the fundamental mode LP_{01} is coupled in DRLPG structure, a numerical simulations should be carried out. As one can find in [35, 37, 38], DRLPG fabricated in conditions described above coupled fundamental mode with LP_{09} and LP_{010} modes when is immersed respectively in water (n=1.3333) and liquid with higher refractive index (more than n=1.3808). The collaboration with above team of authors, gives the verification of the experimental information about the most probably coupling modes.

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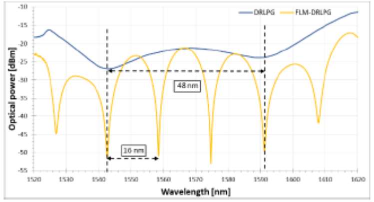

Figure 2. The transmission spectra of the DRLPG (blue) and the DRLPG inside the FLM structure (yellow).

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Authors: Renata Zawisza, Tinko Eftimov, Predrag Mikulic, Wojtek J. Bock, and Leszek R. Jaroszewicz

Dear Editor,

First of all, I would like to sincerely thank the Reviewers for constructive criticisms and valuable comments of this manuscript, which will contribute to improving the quality of this article. Accordingly, we agree with the Reviewers suggestions and have made suitable changes in the manuscript, which are shown as an underlined text. Our responses to the Reviewers all comments are listed below.

Reviewer #1

Regarding English language and style: *Moderate English changes required.*

Answer: All text has been checked regarding English improvements and typos elimination.

Regarding point 1. *Format the figures with the same layout and style. Provide tick marks in both axis.*

Answer: The authors agree with the Reviewer that sufficient care in terms of the Figures formatting was not taken in the original manuscript. The authors have formatted all the Figures, especially 2-6, as recommended by the Reviewer.

Regarding point 2. *To obtain the dual-resonance of the transmission spectrum, the LPG was tuned by etching in hydrofluoric acid:*

- what was the procedure (material and methods)
- what was the final diameter
- why no changing the grating period?

Answer: In this paper, the DRLPG technology is owned by the Photonics Research Center, Université du Québec en Outaouais, Canada, and is protected by IP rights, therefore no more details may be disclosed at this time. We can say that the etching process took place under the controlled conditions: the cladding of the LPG was etched until obtaining the dual-resonance. During this process, the resonant wavelength was shifted up to the dispersion turning point (DTP). The etching rate for the SiO_2 glass and applied HF solution has been estimated using the reference samples, to be 30 nm/min. The diameter of the DRLPG cladding determines the order of the cladding mode to which the fundamental mode will be coupled, assuming a given range of the refractive index in which a given sensor will be working. The LPG consists of the periodic refractive index changes in the fiber core and while the cladding is being etched, the geometry of the fiber core remains unchanged. As an answer to this point we have rewritten the DRLPG description between lines 126-135.

Regarding point 3. *Units of figure 2 and 3a) and 4 are "dBm". That means you did not normalized the LPG output spectrum with the source light? That would mean that some features we see are in fact the spectrum of the source. This point MUST be clarified.*

Answer: Thank you for this valuable remark. We agree that if not normalized, the DRLPG output can be somehow influenced by the spectrum of the source used in the experiment. However, we omitted in the description to mention that in our experiments the source and the OSA are operated using a data acquisition system in the LabView environment, where the reference spectrum from the source was actually subtracted from the output signal. In case of the optical spectrum analyzer, the signal analysis is as follows: the signal from the wideband source was measured as "Trace A", than the signals from the whole setup was measured as "Trace B" and finally, and finally the "Trace C" was observed as a difference between both "Trace B" and "Trace A", respectively. So we indeed did take into account the light source spectrum, however the "dBm" mentioned in the Figures shows our intention to illustrate the real depth of the dips and notches. It is really important remark and we did correct the information in the lines 121-123. The setup schema (Figure 2) was updated to show the system in the LabVew environment.

Regarding point 4. *Figures 3 b) and 4 c) and 5 b) are linear fittings. Those are not very good fitting . A clear explanation must be provided.*

Answer: Figure 3b) represents the influence of the temperature, with linear fitting coefficient equal to 0.978 (corrected value at line 180 regarding the data presented in the Figure 3b), which seem to be a good linearization. The problem exists in the border ranges of the investigated temperature (below 25°C and above 45°C) where flattening of the data is observed. It is probably caused by the properties of the liquid: their evaporating for upper range of temperature as is motioned in lines 185-186, and heat capacity for lower range of temperature which limited hot plate proper operation in room temperature existing in laboratory. It has influenced the data presented at Figure 4c). Regarding the Figure 5b), our results are similar to Chiang C.-C. and Tseng C.-C. (added Ref. [22]). We have added some appropriate comments in the revised paper in the lines 181-185, 215 and 231. We strongly believe that the maximum error of 9% is acceptable for the Reviewer.

Reviewer #2

Regarding point 1. *Although a literature survey was reported by the authors, there are many new long-period fiber grating sensing technique which have been reported recently. The authors should at least acknowledge them, such as packaged long-period fiber grating, ELPFG, NLPFG ...etc.*

Answer: Thank you for your advice, while preparing the manuscript the authors decided to focus on the techniques which are used for RI measuring. However, the Reviewer is right that the indication of other recently published techniques will increase the value of the manuscript. For this reason, we have acknowledged a new LPG techniques in a form of a sentence in introduction shown in lines 53-60, with additional six references [18-23]. In consequence, the second paragraph of Introduction has been divided for two.

Regarding point 2. *As the paper is presented on the basis of experiments, I suggest the authors made a detailed analysis of several performance factors of the proposed sensing device. These are:*

- *Wavelength dependence*
- *Polarization dependence*
- *Stability and repeatability*

Answer: The main idea of our work has been presented previously as mentioned in the lines 75-77. We have paid close attention to avoid our own plagiarism, therefore some problems widely described previously in the cited references are not mentioned here. Regarding the wavelength dependence analysis, it is discussed in slightly modified lines 142-145 and in Figure 2. The conclusion is that by varying the length of the PM fiber we can match the FLM wavelength characteristic to the DRLPG spacing between the notches. The polarization behavior of the fiber optic interferometer in the Sagnac configuration is well known either for the FOG or the FLM configuration (see for example Jones matrix approach presented in Jaroszewicz [29] or Feng S., Mao Q, et al, Opt. Commun. 277, (2007), 322). For the wideband 3 dB coupler used, the input SOP is negligible but the proper fiber loop action depends on the input SOP at the PM fiber, which is controlled by the PC. This aspect is precisely described in the lines 145-150. Finally, we think that the system stability and repeatability is adequately described by all presented experimental investigations in respect to: stress influence – lines 161-166, temperature influence (points 3.1 Temperature response, 3.2 Ambient RI response), unique technique for simultaneous ambient RI and temperature measurement – point 3.3. In conclusion, the estimated error, presented at the end of paper, in our opinion is directly influenced by the system repeatability.

Regarding point 3. *The author should added more detail descriptions about fabrication process of "DRLPG". It is not clear. Such as "laser fluence" "frequency" "beam size" "focus length" "hydrogenating process: pressure? time?" "wet etching process"*

Answer: Thanks for your suggestion, but IP rights to the DRLPG fabrication technology are owned by the Photonics Research Center, Université du Québec en Outaouais, and the details can not be disclosed at this time. However, we have rewritten the DRLPG description in lines 128-135 as an answer to this Reviewer remark.

Regarding point 4. *The illustration of Fig 1 is not sufficient and adequate with your text. I suggest the authors should add detail descriptions about system setup in figure 1. Moreover, is the polarization controller is 2X2? The details of the about "polarization controller" should be descriptions. In fig.1 only shows the schematic setup of sensing system. I suggest the authors should add the real picture of experimental setup and DRLPG sensor.*

Answer: Consequently to our response to Reviewer's comments in point 2, we have tried to avoid plagiarism in comparison to our previous papers. Due to the fact that the configuration used has been described in detail in our paper shown as Ref. [30], in this paper we present only general remarks about the system operation with reference to [30], mentioned in the Introduction (line 77) as well as in the point 2.2 (line 116). The polarization controller (PC) is a common manual fiber PC (Thorlabs' 3-Paddle PC FPC030), which consists of three fractional wave plates created by looping the fiber around three independent spools. The PC uses bending-induced birefringence to create the independent wave plates to alter the polarization of the transmitted light in the SMF. The paddles are configured to approximate a quarter-wave, half-wave, and quarter-wave plate, and it is common to use the PC for a fiber-optic interferometer in Sagnac configuration. The accurate statement has been added in line 115. Regarding the last Reviewer's sentences at this point, the real picture of the experimental setup (Figure 2 b) has also been included.

Regarding point 5. *In page 4 line148 "...the groove was attached to a ceramic hot plate, which was current controlled..." I think the temperature variation is large at the hot plate. I suggested that temperature-PID controlled oven (temperature variation within 1°C) should be used to obtain good experimental datum.*

Answer: Thank you very much for this valuable suggestion. Since our tested DRLPG- based sensor is designed to work when immersed in water (n=1.3333) and in liquid with a higher refractive index (more than n=1.3808), it is required to heat the liquid in which it is placed. For this reason we decided to adopt the groove from which the liquid did not pour out, and the immersing the DRLPG was convenient. After each test, the DRLPG was carefully cleaned by alcohol. Such operation is not possible for proposed temperature-PID controlled oven, Moreover, our approach gives non-directly temperature influence (via water mixture), which thermal capacity limited precisely changes of temperature (below 1°C).

Regarding point 6. *The calibration experiments should be repeated 3 times to show the stability and repeatability in fig 3, 4, 5. I suggest the authors to discuss the deviations of the calibration experiments.*

Answer: Indeed, it is very important to underline the stability and repeatability of the RI and temperature measurement by the DRLPG, PM fiber, as well by the both. We have measured the repeatability of the DRLPG in the fiber loop mirror (FLM) in terms of changing both RI and temperature. When it comes to the wavelength shifting, the errors are estimated to be 0.4 nm and 0.3 nm for RI and temperature changing, respectively The precision of amplitude dips is estimated to be 0.6 dBm for temperature and 0.4 dBm for RI measurement. This conclusion is added as lines 308 - 310.

Thank you once again for devoting time to give the valuable comments and suggestions. We hope that our answers and corrected text are satisfactory for the Reviewers.

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- fonogramów i programów radiowych i telewizyjnych,
- wynalazków we wszystkich dziedzinach działalności ludzkiej,
- odkryć naukowych,
- wzorów przemysłowych,
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- ochrony przed nieuczciwą konkurencją.

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Podstawą wszelkich praw wyłącznych jest ich terytorialny charakter. Oznacza to, że każde prawo dotyczące tego samego dobra niematerialnego funkcjonujące w dwóch różnych krajach jest od drugiego całkowicie niezależne. Możliwe jest, zatem, że ten sam wynalazek zgłoszonych w dwóch krajach zostanie objęty patentem w jednym z nich, a w drugim nie. Możliwe jest też, że te same prawa przysługiwać będą w dwóch krajach różnym osobom. Fakt istnienia, zakres ochrony oraz podmiot uprawniony w jedynym kraju są bez znaczenia dla sytuacji odpowiednich praw w innych krajach.

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z *Ustawy z dnia 4 lutego 1994 r. o prawie autorskim i prawach pokrewnych (Dz.U. z 2018 r. poz. 2245 z późn. zmianami)*

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2) plastyczne;
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6) architektoniczne, architektoniczno-urbanistyczne i urbanistyczne;
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